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ENGINEERING DESCRIPTIVE GEOMETRY AND DRAWING

A TREATISE ON LINE DRAWING, DESCRIPTIVE GEOMETRY, AND ENGINEERING OR MECHANICAL DRAWING, FOR THE USE OF MIDSHIPMEN AT THE UNITED STATES NAVAL ACADEMY

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SIXTH PRINTING, MARCH, 1947

NEW YORK

JOHN WILEY & SONS, INC.

LONDON: CHAPMAN & HALL, LIMITED

1941

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1941 EDITION
Sixth Printing, March, 1947

PRINTED IN U. S. A.

PREFACE

This textbook on Engineering Descriptive Geometry and Drawing is the outgrowth of a long period of evolution in the drawing rooms of the United States Naval Academy. The course of instruction was established between the years 1899 and 1901 by Lieutenant-Commander Frank W. Bartlett, U.S. Navy, on principles still in use.

The subject divides itself naturally into three parts:

Part I. Line Drawing: Teaching the handling of the instruments.

Part II. Engineering Descriptive Geometry: On the rules of orthographic projection applied to the simple geometrical shapes.

Part III. Engineering Drawing: The application of the general principles of drawing to engineering purposes, with the necessary abbreviations and short cuts, and the acquisition of a mass of knowledge of detail in engineering practice.

Parts I and II were written jointly by the late Commodore Frank W. Bartlett, U.S.N., and Capt. T. W. Johnson, Professor of Mathematics, U.S.N., formerly Professor of Mechanical Drawing, U. S. Naval Academy.

Part I, replacing a previous work by the then Lieutenant-Commander F. W. Bartlett, dating back to 1901, has had many revisions to suit changing needs of the U. S. Naval Academy. The final revision of 1941 has added chapters on systematic pencilling, inking, shading, and tracing. Material for a number of practice sheets completes this part.

Part II was written first in 1909 when the subject of descriptive geometry was assigned to the Department of Engineering, to be taught strictly for engineering, not mathematical, purposes. It has had periodic revisions. That of 1941 has much enlarged and systematized the plotting of curved surfaces and the finding of their lines of intersection. It has added a chapter on passing from the formal exact science of orthographic projection to the freedom of the drafting room, where a choice can be made between a number

of ways of expression which make up the art of drawing. For details see the Preface to Part II.

Part III, written by Prof. T. W. Johnson in 1917 and constantly revised, treats of practical engineering drawing. It aims to impart the art of expressing mechanical shapes and, in addition, a number of small items of importance in mechanical engineering, and to put the student in position to acquire easily many more items as he passes into shops and laboratories and sees mechanics at work anywhere.

The revisions of 1936, 1939, and 1941 make every method and every illustration conform to the standards established by the National Screw Thread Commission and the American Standard of Drawing and Drafting Room Practice. The initial chapter, Describing and Dimensioning, illustrates this point. The Tables of Standards are, of course, not complete but they adequately cover the drawing standards, standard bolts, threads, etc., and the standard pipes and fittings as used by the U. S. Navy.

For the features of Part III in detail see the Preface to that part.

Many thanks are due to the officers of the Department of Engineering, U. S. Naval Academy, for their advice and cooperation during the course of this final revision.

T. W. J.

June, 1941

PART I

LINE DRAWING

A TREATISE ON THE DRAWING INSTRUMENTS; THEIR CARE, AND THE MANNER OF USING THEM

CONTENTS

PART I

CHAPTER I

DRAWING ROOM EQUIPMENT

1. The Full Equipment used by the individual midshipman for the drawing courses at the Naval Academy is divided into two parts. One part is the property of the Department of Marine Engineering, and is assigned to the midshipman for his use during his period of study of the subject. This part is discussed in this chapter. Another part is the midshipman's individual set of instruments, purchased, by direction, from the Midshipmen's Storekeeper. It is a set of instruments of considerable value and should be kept in good condition. It forms a necessary part of the equipment of a junior officer in the service after graduation, and is treated of in Chapters II to VI.

2. Equipment Allotted by the Department of Engineering.—This consists of (1) a Drawing Table; (2) a Drawing Desk, or a half share in one; (3) a Stool; (4) Drawing Boards; (5) T-Square. Supplied also through the department, but charged to the accounts of midshipmen, are ink, paper, tracing cloth, and blue-print paper.

3. The Drawing Table.—This "table" is an adjustable stand which may be set to hold the drawing board at any elevation and angle, as shown in Figs. 1 and 2.

Work at this table is almost always done while standing, as it is found more healthful to stand than to sit. For our work the table top should be even more nearly level than shown in Fig. 1. At its proper height the edge of the table should be just below the pit of the stomach, so that, when it is necessary to lean over, the edge does not cut into the abdomen.

If the light upon the table is not **from the left and from slightly in front** (not "over the left shoulder" as for reading) the table should be turned to suit. Note which window or skylight casts the

deepest shadow from any object placed on the table, and turn with reference to that light.

To lower the table a given distance clamp *e*, loosen *d*, raise *c* the distance the table is to be lowered, and clamp it tightly. Then loosen *e*, checking the drop by hand.

4. The Drawing Desk.—This desk is a table, or stand, as much as it is a desk, but since it contains a drawer for ink bottles and a rack for drawing boards it may receive the name "desk" to distinguish it from the adjustable table.

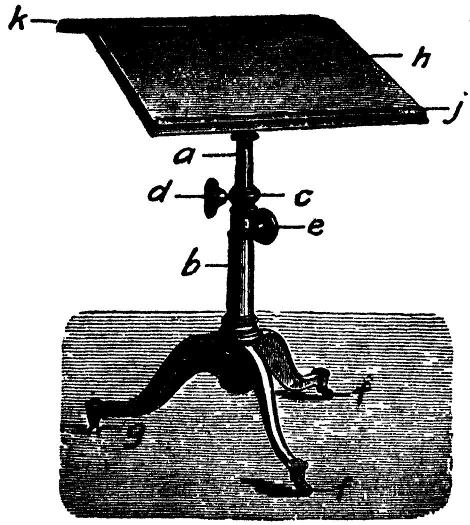


FIG. 1.

FIG. 2.

The flat top is about 30″ square. The numbers by which desks are assigned are on the pedestal of the desk. Round numbers, on the walls of the drawing room, make it easy to locate desks.

5. Drawing Boards.—The pedestal of the drawing desk is divided by battens into a number of slips into which drawing boards are put. These boards measure about 22″ x 30″.

In selecting one which has no work on it, see that no shrinkage cracks have appeared and that the "battens" across the end, which prevent the board from warping, have not become loose. The glue in the joint sometimes dries and loosens. If one side of the board

is varnished, consider that side the back and put the other side up. If the board passes this surface inspection, the next step is to test the working edge. It must be understood that a drawing board is essentially a plane surface **with one edge a straight line.** It is only approximately a rectangle, and three of its edges may be decidedly not straight.

The one straight edge is known as the "working edge" or "true edge." If this edge becomes crooked, by shrinkage or by injury, it must be planed true again by a skilled man using a metal "straight edge" to test his work.

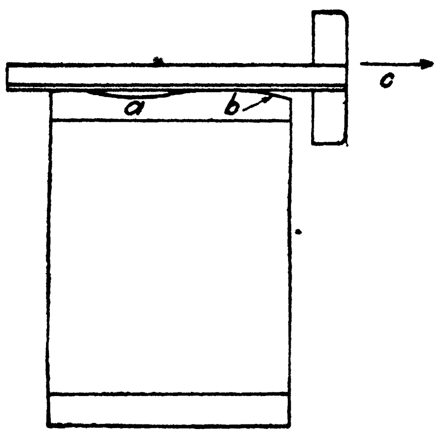


FIG. 3.

6. To Test the True Edge of a Drawing Board.—Look first for evidence of one of the battens having been recently planed off or "trued." Often the true edge is indicated by printing "upper left edge" near it, or by stamping a circle by a sharp die which cuts into the grain of the wood. By whatever means you have selected an edge, test it by using a T-square as a straight edge against it, as shown in Fig. 3. The beveled edge, or upper edge, of the blade of the T-square is turned down, and fitted against the edge to be tested near the top surface of the board. When the board is held up to the light no hollow should be seen, such as is shown, immensely

exaggerated, at *a*, or any low corner, as shown at *b*. The fit should be close everywhere and should remain so when the square is slid along to various positions in the direction of the arrow, *c*.

When the edge has been selected and has stood the test, the board is placed on the stand, or adjustable table, with the true edge to the left, as shown in Fig. 4. Left-handed draftsmen, however, often reverse this and place the true edge to the right.

When sliding drawing boards in and out of the rack, hold them by the working edge with the other batten down, so that any knocks may be received by the other batten, thus saving the true edge from injury.

7. The T-square.—This instrument is shown in position on the drawing board in Fig. 4. While the board has but one true edge, *a*, the square has two; namely, *b*, that in contact with *a*, and *c*, the upper edge of the blade. *c* is approximately at right angles with *b*, but not exactly so, except as the result of chance.

Several T-squares may hang on nails on the three panels which form the sides of the rack for drawing boards. When one of these has been selected for use be careful not to change it, at least not until a new drawing is started.

8. To Inspect a T-square.—First examine the junction of the blade and head. This joint must not be loose, a common defect which may result from dropping upon the floor. The blade must not be too badly warped, though some warping may be unavoidable. Warping can often be corrected by a vigorous bend or twist in the hands tending to produce a bend or twist opposite to that due to warping. The upper edge of the blade, *c*, must not be nicked. Every inch of it should be examined. To test the straightness of the edge, *c*, the same test applies as for the board (see Fig. 3). Testing one blade edge against another, by holding the crack between them up to the light, is also good. Be sure to move one along the other and to try several positions. Blades are not often untrue in this way.

A test of the edge, *b*, of the head is also needed. One of the common defects is a hump in *b*, just under the blade. This is due to the wedging action of the screws. The wood of an old and seasoned T-square may, at any time, after years of use, yield to this

pressure and spread, so that the edge, *b*, which was formerly perfectly true, now has a swelling on it near the screws. Test the square on a board and see that it does not rock when held against the true edge of the board with pressure first at the end, *d*, of the head, and then at the end, *e*. Rocking will cause the end of the blade, *g*, to waver. A less harmful defect and a less usual one, is a hollow, or concave, edge on the head instead of a convex one. This is detected by holding the board and T-square up to the light.

9. Use and Purpose of the T-square.—The square may be slid up and down the edge *a*, Fig. 4, and if *a* and *b* are true edges and kept truly in contact, the edge *c* will move **parallel to itself.** The combination is designed, then, for drawing parallel lines lengthwise of the sheet of paper placed on the drawing board in the usual position. These lines are spoken of as "horizontal lines" on the drawing.

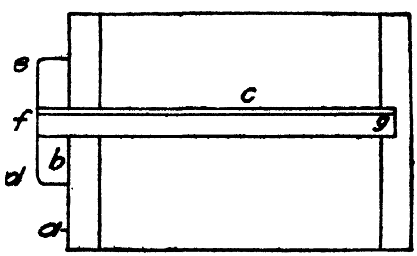


FIG. 4.

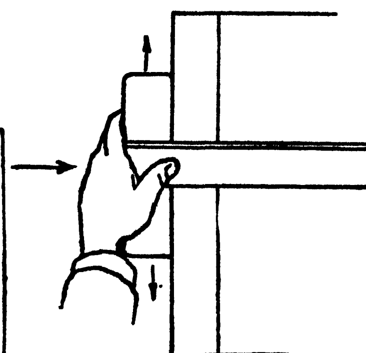


FIG. 5.

This possibility of drawing horizontal parallel lines with ease is the basis of the handling of all the right line instruments. The condition that the edges *a* and *b* should be really in contact is the one difficulty in the handling of the combination. A mere touch to the free end of the blade may tilt it slightly, lifting one corner, *d* or *e*, from contact with the edge *a*, by so small an amount as not to be noticed. The divergence of the supposedly parallel lines will spoil the accuracy of the drawing and perplex the draftsman until the error is discovered and remedied. The way to prevent this

annoying fault is to form a habit of handling the T-square properly. The T-square must be **moved only by its head,** as in Fig. 5, with pressure to the right to keep the edges in close contact. When it has been moved to the right place, the hand may be slid along the blade to clamp it against the board and hold the position while other instruments are adjusted against it. Fig. 6 is the **position for clamping the blade,** not for moving it.

Make it a rule never to move the square by the blade, but always by the head, and you will avoid many perplexing inaccuracies.

10. Left-Hand T-square.—Some left-handed draftsmen use the right hand T-square and devise their own modifications of the handling of the instruments to suit themselves. Others use the left-hand T-square and reverse all the instruments used with it, including the drawing board. The left-hand T-square has a true edge on the other side of the blade, so that when the square is placed with the head to the right, the true edge will be the upper edge of the blade. Left-hand T-squares are not served out at the original time of allotment, but are kept in stock and served out on application. The novice in drawing, who is left-handed, might well try each kind and find which suits him better.

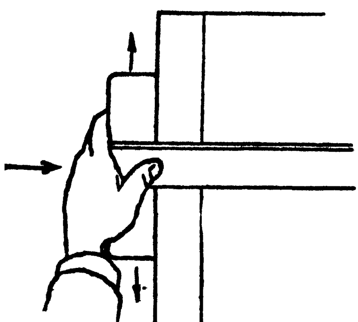


FIG. 5.

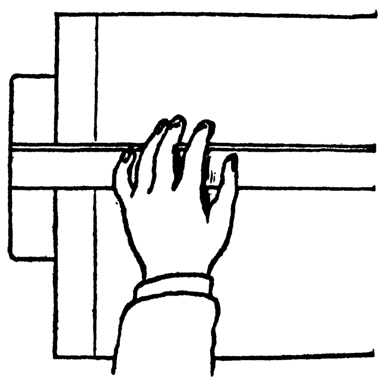


FIG. 6.

11. Drawing Paper.—Drawing paper is of many qualities and is usually white or buff. For drawings which are to remain a long

time on the boards, subject to much erasure, a heavy white paper of high grade is needed. Such paper is used at the Naval Academy for the first drawings.

To help members of the class who have lost time by absence or otherwise, paper ruled in inches and eighths may be issued in special cases, at the discretion of the instructor.

12. Position of Sheet on Drawing Board.—A sheet with its length placed parallel to the length of the drawing board is said to have its long dimension "horizontal." One with its length at right angles to that of the board is said to have its long dimension "vertical." Although the drawing board is almost level while a drawing is being

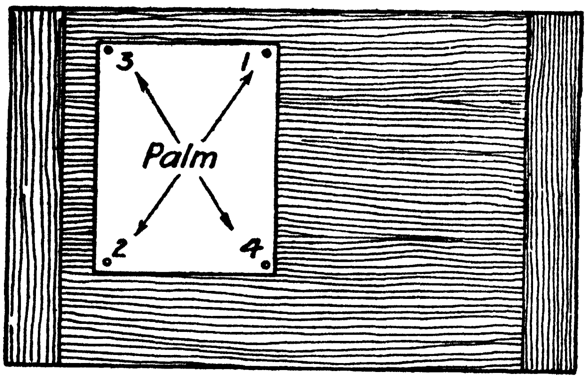


FIG. 7.

made on it, the presumption is that a drawing, when being examined, is held up vertically before the face, and the terms "horizontal" and "vertical" refer to this position. They are very common terms in the drawing room in this sense.

13. Thumbtacking a Small Sheet to the Drawing Board.—A small sheet may be held securely by four thumb tacks in the four corners. In Fig. 7 such a sheet is shown placed with long dimension vertical. It is placed above the middle and nearer the left edge than the right edge of the board. This position makes the handling of T-square and other instruments easier than a central position would

do. The putting in of the pins is shown in Fig. 8. At the center of the sheet, marked "palm" in Fig. 7, the palm of the left hand is placed and its pressure holds the paper to the board while the pins are inserted in the order of the numbers. In each case the right

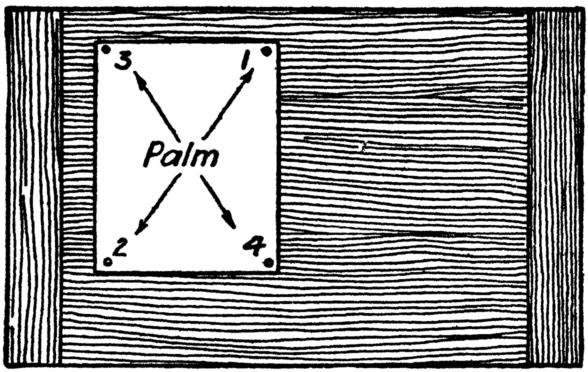


FIG. 7.

palm smooths the paper first from the center of the sheet to the corner, as indicated by the arrow in Fig. 7. In placing the thumb tack, ready to push it home, incline the point of the pin a little out,

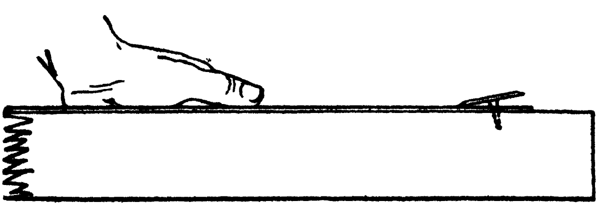


FIG. 8.

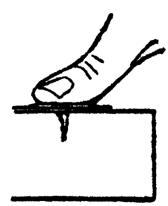


FIG. 9.

or the head in. In pushing the pin home apply pressure and straighten it at the same time, as in Fig. 9. This action draws the paper with it and tightens it between center and corner. Without lifting the palm of the left hand between opposite pairs of tacks, insert 1 and 2 first, and then 3 and 4.

14. Thumbtacking a Large Sheet of Paper to the Drawing Board.—A large sheet of paper, approaching the size of the drawing board, requires at least six tacks to hold it. Two more tacks are added at the middles of the long sides, and they are the first inserted, giving the order of application shown in Fig. 10.

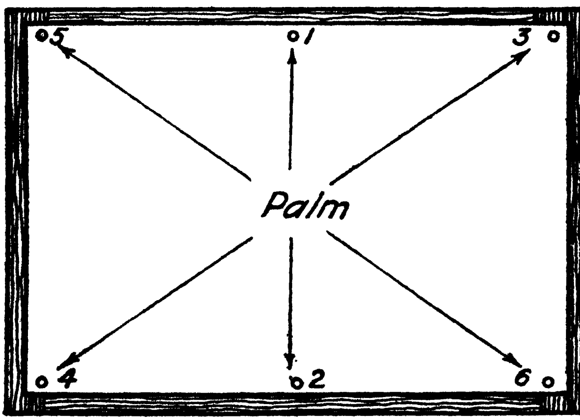


FIG. 10.

15. Buckling of Drawing Paper.—Heavy paper is often buckled slightly. That is to say, there are small humps in it and it does not lie perfectly flat. Even if tightened enough to show no buckling when first tacked to the board, as the weather changes and damp and dry days alternate, the paper will stretch and become buckled. Only when this defect is very decided should any attempt be made to remedy it. A slight buckle is an annoyance, but it is far less of an obstacle than one at first imagines. Fortunately it has little effect on the accuracy of the drawing. However, a very badly buckled sheet must be taken up and retacked completely even if the drawing is well under way.

A buckled sheet may be stretched by loosening the three thumb tacks on one edge, smoothing the sheet from the center, replacing the three tacks, and then loosening the three on the opposite edge and replacing them in the same way.

16. Tacking a Small Temporary Sheet Over a Permanent One.—In Fig. 11, a small sheet, such as those used for monthly examinations, is shown applied over a drawing already in place. The new sheet is held by three tacks only. The large sheet is represented as

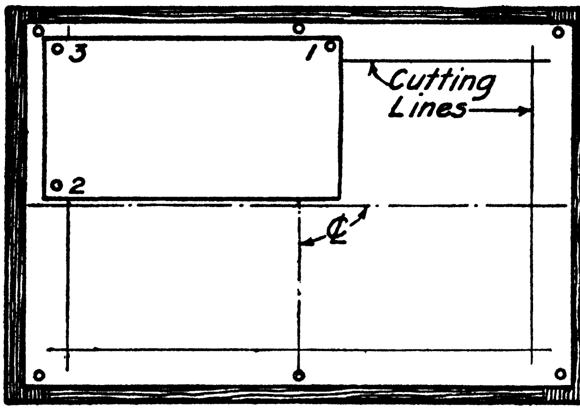


FIG. 11.

having drawn upon it the horizontal and vertical center lines and "cutting lines," which give the size to which the large sheet is ultimately to be trimmed. Outside the cutting lines, which form a rectangle, the paper is waste paper, the so-called "waste margins." Note that the small sheet is applied in the upper left corner, covering part of the cutting lines of the large sheet, and that the three tacks used pierce only the waste margins of the large sheet. Tack No. 4, Fig. 7, is omitted, as it would injure the large sheet in a conspicuous place.

CHAPTER II

SET OF INSTRUMENTS. PENCIL INSTRUMENTS

17. Instruments Purchased by Midshipmen.—The equipment purchased by midshipmen consists of a box of instruments, a sketch book, text-book, and cloths for covering drawings. The subject of this chapter is the set of instruments, particularly the instruments for making pencil drawings.

18. The Box of Instruments.—This leather covered wooden box measures 14″ x 6″ x 3″.

At an early opportunity mark this box, by stencil or other method, with name, in large letters, and also as many of the instruments within as you can find place and means to mark.

19. Care of Instruments.—The steel and German silver instruments are kept clean and free from rust and tarnish by rubbing them occasionally with chamois skin or, if necessary, with a piece of crocus cloth stripped from the pencil-sharpening pad. New instruments have a high polish and, with a reasonable amount of care, will look well for years. It will pay to keep the instruments clean and in repair from the very first, and, when any are injured, used up, or lost, to repair or replace the defective parts. Inattention to this rule will create a handicap during examinations or in the daily work. Instruments must be in good condition to do good work.

20. Classification of the Instruments.—The instruments as a whole may be subdivided into four main classes as follows: (1) Those for making pencil lines, (2) those for making ink lines, (3) those for taking dimensions, and (4) flat instruments for guiding either pencil or pen. The remainder of this chapter is on the first of these classes.

21. Instruments for Making Pencil Lines.—These are, in the instrument case, the compass, the bow pencil, and the lead holder;

and, in the big box, lead pencils, pencil-sharpening pad, rubber eraser, artgum cleaner, etc.

22. The Compass.—This is the most noteworthy of the pencil instruments. Its function is the drawing of large circles. The usual form of the instrument is shown in Figs. 12-15.

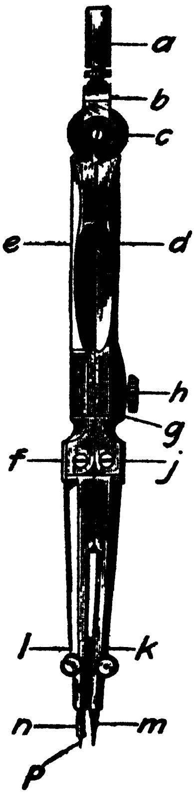


Fig. 12.

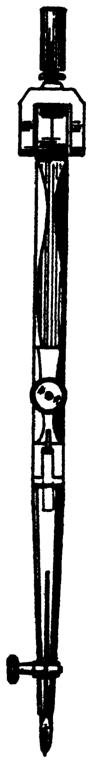


Fig. 13.

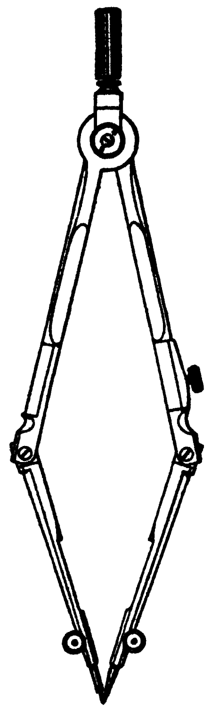


Fig. 14.

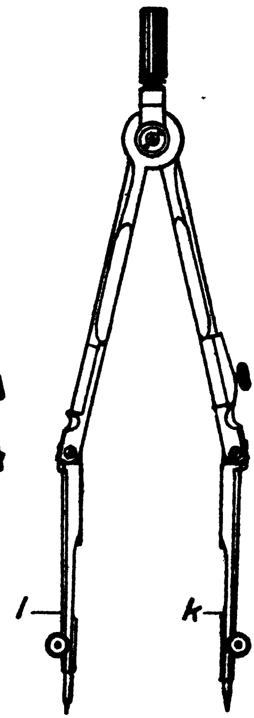


Fig. 15.

Fig. 13 is the side view of the instrument. Fig. 14 shows it bent into a form for testing the alignment of the three hinges to see that all work in the same plane. When so bent, the needle and the lead should touch; one should not be above the other or nearer to the eye.

Fig. 15 shows the instrument bent as it should be for drawing

a circle of moderate size. The joints at the knees should be bent, or "broken," so that the pencil and the needle points are parallel to each other and perpendicular to the paper. To set the instrument for drawing a large circle, first separate the knees approximately to the size of the radius required. Then bend the knees to bring *l* and *k* parallel. A fine adjustment must now be made by the joint at the head in order to fit the instrument to the exact radius required. The joints in the knees are put there for use, and the attempt to use the instrument stiff-legged leads to many errors.

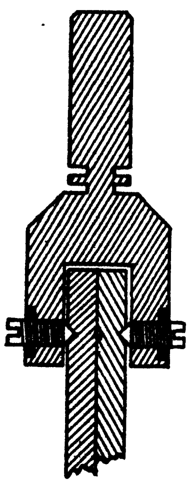


FIG. 16.

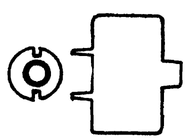


FIG. 17.

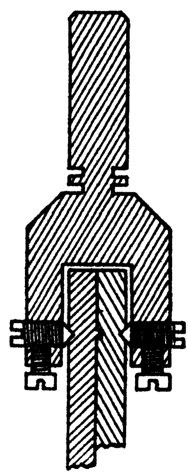


FIG. 18.

The shank of the needle, *n*, is often made in the form of a screw, and a raised collar with roughened rim, at the place where the line from the letter *n*, in Fig. 12, touches it, makes it easy to turn the screw and adjust it. This screw needle rarely "slips" from the pressure against the paper.

23. The Joint at the Head of the Compass.—A section of this joint is shown in Fig. 16, in the form known as the "Esser Joint"; and, in Fig. 18, in the form known as the "Alteneder Joint." They differ only in the manner in which the joint is locked against becoming accidentally loosened in use.

Rotation between yoke and head will have a tendency to unscrew one or the other of the pivot screws and, without a locking device, the instrument would be constantly becoming too loose. The small blued-steel washers in the Esser joint, or the small set screws in the Alteneder joint, when screwed up, lock the pivot screws fast.

Fig. 17 shows the screw driver designed to turn the pivot screws and the threaded washers (lock nuts) of the Esser joint.

Never use oil in any joint of the compass. If it is too tight, reset it by first loosening a lock nut or set screw, and then very slightly loosening a pivot screw. When correctly adjusted, tighten up the lock nut or set screw again. It may be necessary to try this several times before hitting the correct adjustment. If set too tight, it is difficult to adjust to a desired radius. If set too loose, the radius will change in use and spoil the work.

24. Use of Compasses.—Although this subject precedes the instructions for sharpening the lead for the compass (see later, Art. 35), the general method of handling the compass is discussed here so that the first tests may be made on scratch paper. Put the instrument in the position of Fig. 15. Prick a small hole in the paper with the needle, forcing it down to the shoulder. Hold the compass perfectly upright. Grasp the handle between thumb and forefinger and give a twist, turning the compass "clockwise." At some point in the circle the pencil lead is likely to leave the paper and whirl around without making a mark. Obviously this method of handling does not give the proper control. Modify the handling thus: Lean the instrument forward slightly, so that the handle is in advance of the lead in the direction of motion. Now put the twist on the handle. This time the lead will tend to press down on the paper and the needle to fly up. The needle, however, is hooked in the paper and resists this tendency, while the pressure on the lead prevents motion. Now make the handle describe a circle in the air, a little in advance of the lead, maintaining the twist on the handle by means of the thumb and forefinger. The line drawn will now be fully under control, both as regards amount of pressure and rotation.

25. The Bow Pencil.—The usual form of this instrument is shown in Fig. 19, and a second form having a "central thumb screw" is shown in Fig. 20. It is a form of compass for drawing

small circles, and for work within its range it is far more handy than the large compass. When properly handled it can describe circles that seem at first to be mere dots on the paper.

The adjustment of many scientific instruments is made in two steps, the "coarse adjustment" and the "fine adjustment." The

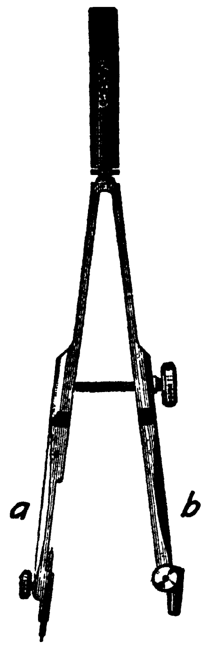


FIG. 19.

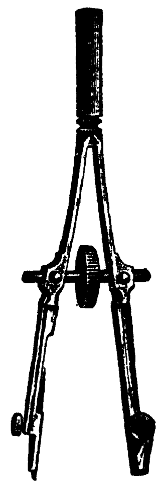


FIG. 20.

bow pencil illustrates this principle well. To make a large change in the setting of the instrument, first make a coarse adjustment by pinching together the two points *a* and *b* by thumb and forefinger of the left hand, and giving a rapid twirl to the thumb nut with the other hand. The nut will continue to rotate rapidly, and when it has traveled along its screw to about the place where one's judgment dictates, release the grip of the left hand, throwing pressure again on the thumb nut. Fine adjustment can be made by turning the thumb nut carefully and slowly while comparing the radius of the

instrument to the desired distance by scale. The thumb nut is purposely made very loose on its screw to facilitate the coarse adjustment.

The figures show both forms of bow pencil empty of leads.

26. Needles for Compasses.—The needle supplied with the bow pencil and other bow instruments is always a very fine one. The hole which it makes in the paper when shoved home to the shoulder, is smaller than the width of the ink line used in standard drawings. In practical work many centers for circular arcs lie on the lines of the drawing, and all such will be completely concealed by the ink line. A center for a circle will not cause an ugly bulge in it.

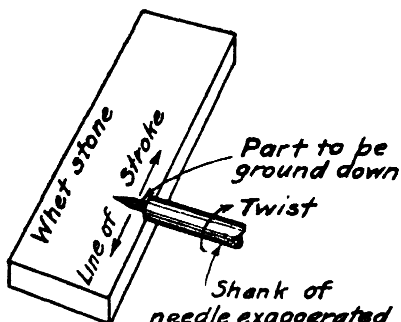


FIG. 21.

The needle for the large compass should be of the **same size** as that of the bow pencil. The cylindrical barrel or shank is much larger, but the actual needle point should be the same. If fitted into a hole made by the bow pencil it should not enlarge it, nor should the needle of the bow pencil be loose in a hole made by the compass needle. If the needle proves too large, as it is apt to do, one must either use it without pushing it home, or, better, grind it down to the smaller size. To do this wet one of the edges of the oil stone, put the needle with its shoulder against this edge and move it along the edge, twirling it between thumb and forefinger. Continue this until the actual needle point fits the holes made by that of the bow pencil. See Fig. 21.

The large compass and the bow instruments may have to use the same center many times alternately, and it is very desirable to have the needles exactly of the same size.

27. The Scale of Leads.—In addition to the leads for the compass and bow pencil, others must be provided for drawing the straight lines, etc. Pencils suited for mechanical drawing must be of very superior quality, and are all hard pencils, much harder than those used for ordinary purposes. The complete series of lead pencils, for all possible purposes, are graded in 13 or more kinds. The designations usually used are H for hard, graded from H to 6H, and B for soft, graded from B to 6B. HB or F is medium, between the two series. Commercial pencils are often numbered 1, 2, 3, and 4. They correspond roughly to 2B, HB, 2H and 3H. Draftsmen prefer the pencils from 2H up, and the favorite is 4H for work on white paper. In general, there are two main purposes for which we need pencils; sketching, for which the 2H is admirably suited, and drawing, for which the 4H is the standard. Sketching is the making of drawings largely free hand, and often on top of ruled lines already on the paper. The 2H makes a darker mark than the 4H, but not so accurate and fine a line, nor so clean a drawing. A commercial No. 3 is a good sketching pencil. We have then the following table of pencils and their ordinary fields of use:

6B, 5B, 4B, 3B, 2B, B, HB, H, 2H, 3H, 4H, 5H, 6H, etc.
No. 1 (2B), No. 2 (HB), No. 3 (2H), No. 4 (3H)

$\underbrace{\text{6B, 5B, 4B, 3B}}_{\text{Artistic pencil work}}$ 2B ↓ Pencilling on tracing cloth $\underbrace{\text{B, HB}}_{\text{Ordinary writing}}$ $\underbrace{\text{H}}$ 2H ↓ Stenographic reporting $\underbrace{\text{2H, 3H}}_{\text{Sketching (mechanical)}}$ $\underbrace{\text{4H, 5H, 6H, etc.}}_{\text{Drawing (mechanical)}}$

It may be well to mention that these "leads" are not the metal lead or any derivative or compound of it. A form of carbon, "black lead," is used now, instead of the actual metal once used.

28. The Sketching Pencil. H, 2H, or 3H, etc.—This pencil is used in a manner similar to the use of the ordinary writing pencil, and it is sharpened like it, but with more care. Using any ordinary penknife, or the steel eraser, cut away the wood and expose the lead for at least 1/4″, taking pains not to attempt to sharpen the lead

with the steel blade. To do so rapidly dulls the steel knife edge and causes great risk of the lead snapping off. A much better tool for this sharpening is the sharpening pad, and the method of using it is explained below. In cutting the wood from ordinary wood sheathed lead pencils, be sure to cut from the end which has no lettering stamped on it. Let the maker's marks remain on the uncut end so that the quality of the pencil can be identified at any time, even when the pencil has been used up to a short length.

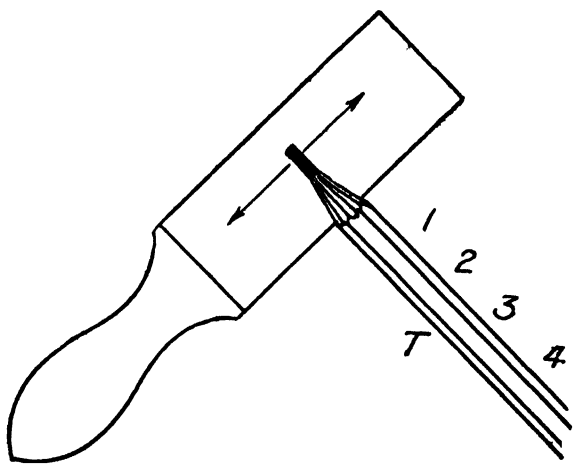


FIG. 22.

29. The Pencil-Sharpening Pad.—A wooden piece, with blade and handle, in the form of a paddle, has glued to one side of the blade a pad of emery paper, and to the other a pad of crocus paper. A flap of black cloth serves as a cover to the pads. It is wrapped around it when put away so that loose graphite may not soil other articles with which it is in contact. Remove, by means of the knife blade, the top covering of cardboard on each side. The black side is the coarse emery and the red side is the crocus paper. The emery is intended for the rapid cutting of the lead, the "coarse adjustment," and the crocus for the "finishing cuts," or "fine adjustment." Many draftsmen are satisfied with the emery alone, but they use

the part of the pad which has become choked up, and filled in with graphite from previous sharpenings, for the fine cuts.

The crocus paper can be used also for sharpening pen points and for cleaning rusty instruments, as will be shown later.

30. Sharpening the Sketching Pencil.—The exposed lead must be sharpened into a long, sharp cone. The actual tip, however, is not brought to a point but left very slightly rounded. This long cone is made by rubbing the lead on the sharpening pad, holding it at a very acute angle with the surface of the pad, and drawing it sidewise across the surface of the pad, **at the same time twirling it on its own axis.** Hold the pad in the position of Fig. 22, and hold the pencil with the tips of the fingers of the right hand, in order, at the

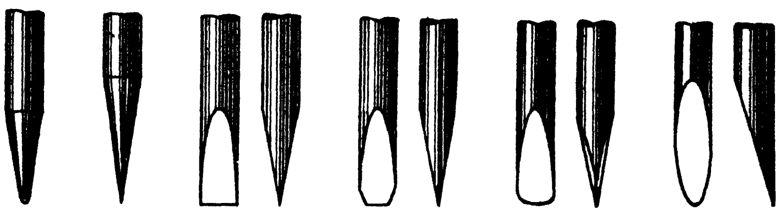


FIG. 23. For sketching. 2H pencil.

FIG. 24. For taking dimensions. 2H or 4H.

FIG. 25. Broad chisel, 1st step.

FIG. 26. Narrowed chisel, 2d step.

FIG. 27. Duckbill chisel, 2d step.

FIG. 28. Elliptical sharpening (bow pencil).

For 4H pencil for drawing on unruled paper.
For 2H pencil for drawing on cross-section paper.

points *1*, *2*, *3* and *4*, the thumb at *T*. The pencil can easily be rolled between the fingers so that it turns first in one direction and then the other.

Fig. 23 shows the cone point left rounded by wear, as it is commonly used for sketching. Fig. 24 shows the sharpening continued until the lead feels as sharp as a needle when tested by pressing to the back of the hand. A well sharpened cone point is a good substitute for a needle or pricker for taking dimensions from the scale.

In sharpening, use the emery paper first for rapidity and later finish on the crocus paper to produce a clean cone without loose flakes of graphite adhering to it. After a cone is well formed, as it

dulls with use, the point can be restored by using only the crocus paper until the angle of the cone becomes too blunt and it is necessary to cut away more wood and make a fresh start. In general, any sharpening, when once well made, can be kept up by little touches to the crocus paper, until the general form is so blunted that a fresh start is needed.

31. Sharpening the Drawing Pencil. 4H-6H.—For the regular work of drawing, the cone pointed pencil is not used. If sharpened fine enough to make lines as narrow as are required for good work, the cone wears too fast, and no one has the patience to resharpen so constantly. Several kinds of chisel points are in use instead.

FIG. 23. For sketching. 2H pencil.

FIG. 24. For taking dimensions. 2H or 4H.

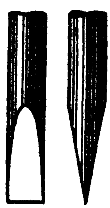


FIG. 25. Broad chisel, 1st step.

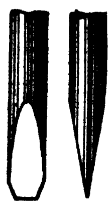


FIG. 26. Narrowed chisel, 2d step.

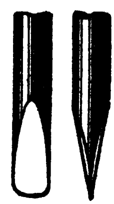


FIG. 27. Duckbill chisel, 2d step.

FIG. 28. Elliptical sharpening (bow pencil).

For 4H pencil for drawing on unruled paper.
For 2H pencil for drawing on cross-section paper.

These may be sharpened to a fine edge, and when moved over the paper in the direction of the edge make a very fine line without too rapid wear. A yard or so of line can be drawn without resharpening.

Selecting a suitable pencil, remove the wood as usual, exposing at least $\frac{1}{4}''$ of lead. Proceed to sharpen the lead as described next.

32. Straight Chisel Sharpening, Narrowed.—Most draftsmen use this sharpening or the next, which is a variation of it. Hold the lead at an acute angle with the emery pad and stroke it along the pad without twirling, keeping a firm hold, and without too much pressure. When the cut has reached the center of the lead turn the pencil over and take a similar cut on the opposite side.

The two cuts meet at the extremity of the lead along a diameter of the original circular end, as shown in Fig. 25. This sharpened diameter, left as a ridge, is the wearing edge of the lead. It is a bit too wide, however, for convenience. After giving the two sides a finishing cut to smooth them, turn the pencil 90° to bring one corner against the pad and give a very light stroke. Treat the other corner in the same way and the narrowed chisel of Fig. 26 will be produced, ready for use.

33. Duckbill Chisel Sharpening.—This variation is produced by combining the finishing cut with the narrowing of the chisel in one operation. Make the coarse sharpening by the emery pad as before. While taking the finishing cuts on each side, rock the pencil very slightly. This rocking is like the twirling for the cone sharpening, but is a matter of only a few degrees of rotation in each direction. The effect is to round the two flat surfaces slightly and to form a chisel edge curved much like the bill of a duck. This form is shown in Fig. 27. It is the form used for stone chisels or hatchets in pre-historic times. The duckbill chisel does not require such close attention while shaping it as does the narrowed chisel and may be preferred as a labor-saver. The two kinds of chisels draw equally well.

34. The Elliptical Sharpening.—Some draftsmen, especially those using the "artist's pencil," a holder for leads, use a sharpening of another kind. This consists of a single cut, like the first one of the chisel edge, but extended to twice its length. The exposed lead must be at least 3/8" long and the sharpening continued until all trace of the former flat end to the cylinder is cut away. Make the coarse cut on the emery and the fine on the crocus paper. The result is as shown in Fig. 28. The plane of the cut forms a long ellipse with beautifully rounded ends. The drawing edge is somewhat similar to that of the duckbill form. Those who use it claim that the leads, as manufactured, are hardest on the surface and that this makes use of the hardened skin to the best advantage. Moreover the sharpening requires far less attention than any other in forming it. Only be sure that the angle of the cut is acute enough, and continue until all trace of flattening across the end has disappeared.

35. Sharpening the Lead for the Compass.—Narrowed chisel, duckbill, or elliptical sharpenings are permitted. The chief point to observe is that the chisel edge must be at right angles to the radius of the instrument and therefore tangent to the circle which is being drawn. Otherwise, a wide line is drawn.

36. Sharpening the Lead in the Bow Pencil.—Only one sharpening is permitted for this instrument, the elliptical sharpening, and the cut must be on the **inside.** Be sure that about 3/8″ of lead projects, and open the bow pencil to its limit. Hook the instrument over the sharpening pad, as shown in Fig. 29, and proceed to cut down to the line *AB*. The angle at which the lead holder

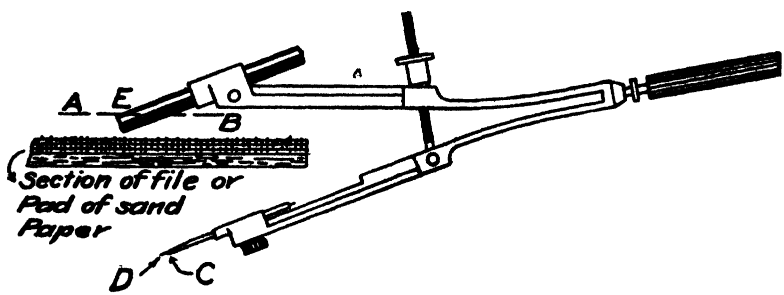


FIG. 29.

of this instrument has been placed has been designed in reference to this sharpening. With the cut on the inside, the edge will be approximately perpendicular to the paper for all sizes of circles within the range of the pencil. The pressure on it will not break it, and when wear occurs the magnitude of the radius will not increase as it would if a sharpening symmetrical to the axis of the lead were used. The very narrow rounded end of the elliptical sharpening can describe circles of minute size. No wide chisel can draw a small circle without making a wide line, for the corners swing out like the ends of a street car when rounding a curve.

It is easy to judge the condition of this sharpening at any time. If a flattening across the end is seen, it needs at least a touch on the crocus paper to restore the edge to proper shape.

37. Adjustment of the Needle of the Bow Pencil.—As soon as the sharpening of the bow pencil is finished, the needle point should be run out to match it. This will take the needle almost out to the limit. There is a great advantage in having both lead and needle project far from the instrument. The handling is easier and one can see the work better. The needle should be so adjusted that when the legs of the instrument are pinched together in the fingers the lead should touch the needle point about half-way between point and shoulder. In Fig. 29 the point *E*, the working edge left after the sharpening, should touch the needle half-way between *C* and *D*. Note that the needle is represented as flattened towards the lead, so that no shoulder remains on that side. This is to permit a radius of almost zero size.

38. Trial of Pencil Sharpenings.—At this place it will be well to test the pencil sharpenings by drawing a few circles with the compass and bow pencil on scratch paper and by ruling a few lines with the pencils. Art. 24 describes the proper way to handle the compass and the bow pencil. The other pencils are always used with some form of guiding edge, the T-square, triangles or other instruments described later under the name of Flat Instruments, in Chapter V.

A recapitulation of the sharpenings, or tabulation, is as follows:

1. *For Sketching.*—2H, or No. 3 or 4. Cone point, rounded end.

2. *For Pointing off Distances.*—2H or 4H. Very sharp cone point.

3. *For Drawing on Unruled Paper.*—4H. Narrowed, duckbill or elliptical chisel.

4. *For Drawing over Ruled Lines.*—2H. Narrowed, duckbill or elliptical chisel.

5. *For Compass.*—4H (or 2H over ruled lines). Narrowed, duckbill or elliptical chisel.

6. *For Bow Pencil.*—4H (or 2H over ruled lines). Elliptical, cut on the inside only.

39. Manner of Holding the Drawing Pencil.—To draw properly the pencil must be held **practically vertical,** inclining but very slightly in the direction of motion. The right hand draftsman should draw his horizontal lines from left to right, and the blade of the chisel edge must be held in the line and not allowed to become slanted across it. The pressure on the paper must be sufficient to make a good visible line in spite of the fact that it is a line of excessive narrowness. Pressure towards the T-square should be only enough to hold the lead in contact with the edge.

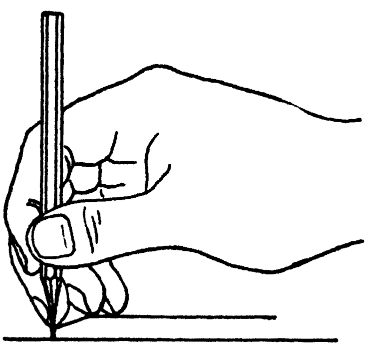


FIG. 30.

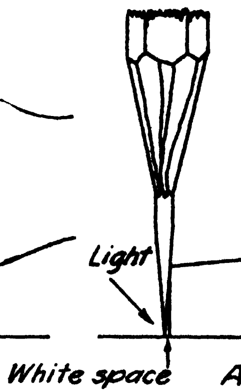


FIG. 31.

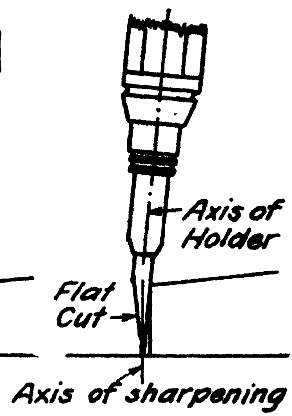


FIG. 32.

Fig. 30 shows the pencil held properly. It is shown as seen from the left, looking along the blade of the T-square. Fig. 31 is an enlarged detail, showing the direction of light required to illuminate properly the edge of the T-square and the line being drawn. Fig. 32 shows the slight inclination which must be given to the axis of the pencil when the elliptical sharpening is used, due to its non-symmetrical form. This inclination is in addition to the slight inclination in the direction of motion, and its effect is to keep the actual axis of the drawing blade vertical, so it is not a real exception to the rule to keep the pencil vertical. In Fig. 32 the rounded or natural surface of the lead is put against the T-square, not the cut surface. This lead is represented as held by the artist's pencil or

lead holder, used by many draftsmen in place of the ordinary pencil.

Note that the grasp of the fingers, as shown in Fig. 30, is a light one. It is not a tight clutch. The middle finger is nearly straight, not bent sharply at the last joint, and it touches the pencil far down towards the drawing edge. The tips of the third and fourth fingers slide along the blade of the T-square, as the line is drawn.

The grasp of the pencil in drawing is utterly different from that natural for writing, and must not be confused with it.

40. Relation of Line Drawn to Guiding Edge.—In both Figs. 31 and 32 it can be seen that the drawing edge is not truly in contact with the blade of the T-square. The contact with the lead is at the upper edge of the blade, not the lower edge where the blade is in contact with the paper. The pencil line, therefore, stands away from the edge about one hundredth part of an inch. Draftsmen soon get used to this distance and never try to reach in with the drawing edge in order to draw a line deep in the crack between the paper and the blade of the T-square. In setting the edge to draw a line through a given point, keep the blade below by this distance. One should always see a streak of white between the line drawn and the actual edge of the T-square. This rule is to be observed with all the instruments used for guiding the pencil.

When the T-square is used as the guiding edge, the light must come from somewhere in front of the draftsman in order to illuminate the edge in contact with the paper, as seen in Fig. 31. In the same way, when we come to draw vertical lines, we shall see that the light must come from somewhere to the left. This is the origin of the rule for lighting given in Art. 3, that the light should come from the left and from slightly in front.

41. When to Resharpen the Lead Pencil—Draw a number of trial lines with the aid of the T-square on a piece of scratch paper. Note the condition of the lead after a little use. Watch the line drawn. As soon as the line widens and gets "fuzzy," lacking in sharpness of outline, it is evident that the pencil needs a complete or a partial resharpening.

One can tell also from the condition of the lead itself. If the duckbill, or the elliptical sharpening, is being used, as soon as any

distinct flattening of the drawing edge is noticed it is an indication that it is time to touch up the sharpening on the smooth side of the sharpening pad. If the lead is pointed straight to the eye, and a highly polished point, reflecting the light, is seen, it is evidence that there is a need of resharpening.

42. Rules for Pencil Work:

1. *Keep Pencil Sharp.*—Lines must be clear but show no thickness. Resharpen whenever the line drawn is defective. Resharpen whenever a shiny reflection is seen when the end of the lead is pointed straight towards the eye. It signifies a flat spot. If the duckbill or the elliptical sharpening is used, resharpen whenever a flattening of the curved edge is noticed.

2. *Keep the Sharpening Pad Always at Hand when Pencilling.*—Have an established place for it and always keep it there. For example, the left end of the shelf to the table top. The pad may be kept with its handle projecting over the edge ready to be grasped by the left hand for sharpening operations.

3. *Retouch Sharpening After a Yard of Line or So.*—See last article. Make it habitual to retouch the sharpening on the crocus paper at very frequent intervals.

4. *Expose New Lead and Resharpen Whenever Lead Becomes Less than 3/16" Long.*

5. *Never Go Backwards over a Line.*—Redraw it in the forward direction.

6. *Don't Press the Lines Into the Paper and Make Actual Grooves in It.*—If the pencil is sharp it will not be necessary to do this. It prevents proper erasing afterwards, since the dent will remain even after all the graphite is removed.

7. *Erase Pencil Lines with Emerald or Ruby Rubber.* Clean large areas with Artgum cleaner.

CHAPTER III

SET OF INSTRUMENTS. INK INSTRUMENTS

43. Instruments for Drawing Ink Lines.—In this class are the right line pen, compass with pen point in place, the bow pen, and ordinary penholder, and pen points. For sharpening pens there is also the oil stone. Rubber ink eraser, erasing shield and steel

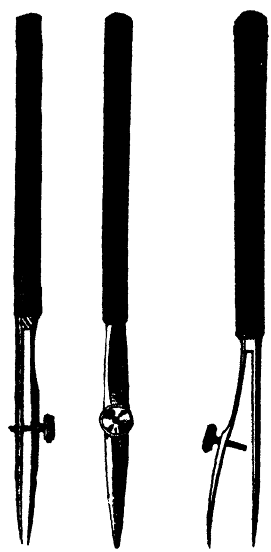


Fig. 33.

ink erasing knife belong to the class of ink instruments since they are used to repair faulty ink work.

44. The Right Line Pen, or Drawing Pen.—Fig. 33 shows three views of a right line pen, namely a left side view, a front view and a right side view in which the thumb screw has been unscrewed, releasing the blades and allowing them to spring apart for cleaning.

This is the unstrained position of the blades. One blade is much stiffer than the other, and, when the screw brings them together, the spring blade moves nine-tenths of the distance. In using the pen the stiff blade is the one which presses against the guiding edge. The spring blade would yield too much and make the ink line vary with every variation in pressure.

When screwed until they touch, the blades should have the shape of the duckbill sharpening of the lead pencil. Each blade, examined separately, should show a smooth elliptical point. Any flatten-

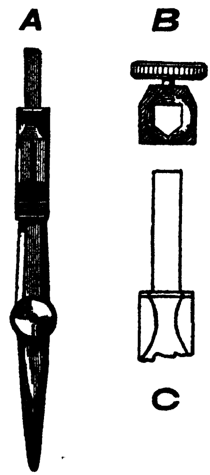


FIG. 34.

ing indicates a break or excessive wear. The blades are made of highly tempered steel, and will snap easily if dropped on the points. As we see from Fig. 33 that the blades have been put under a strain in screwing them until they touch, or nearly touch (for in use the blades should never quite touch), it is evident that if we screw them into forcible and very tight contact we run great risk of causing the tips to snap short. Tempered steel is brittle compared to untempered steel, and must not be put to such severe abuse. Young draftsmen often thoughtlessly screw up their pens tightly as if this were the natural way to keep them, and by so

doing they sometimes break or bend the points. A new pen should receive a preliminary examination to see if it is outwardly perfect.

45. Stainless Steel Pens.—A recent improvement in drawing pens is to make them of stainless steel. Such pens never tarnish from the moisture of hands or from exposure to the weather. Stainless steel pens outwear ordinary steel pens and more than double the time of service before resharpening is required. For this reason one is furnished with the Naval Academy set. Stainless steel bow instruments can be obtained at some increase in cost.

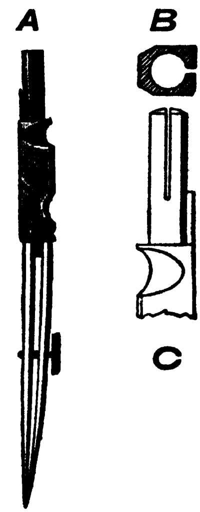


FIG. 35.

46. Compass Pen Points.—The compass, as shown by Fig. 12, has a "slip-joint" at *g* and a set screw at *h*. To convert it to an ink instrument, release *h*, draw out the pencil leg, *k*, and replace it by the "ink leg," or "pen point," shown in Fig. 34. This design has the "pentagonal slip-joint." At **A** is the leg, at **C** an enlargement of the shank and at **B** the pentagonal socket in which the shank slips, and the set screw to secure it.

Fig. 35 shows another design of compass pen-point, one having a "round" slip-joint." **C** is an enlargement of the round shank

with a feather projecting to the right, and **B** is the round split socket it fits.

47. Bow Pen.—The usual form of the bow pen is shown in Fig. 36 and the form with central thumb screw in Fig. 37. They are similar to the corresponding bow pencils with the alteration of the drawing point. With a new instrument, examine the pen point for imperfections. Also adjust the needle so that the pen point

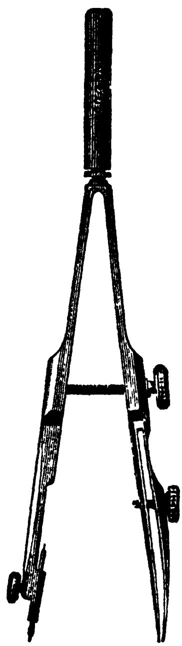


FIG. 36.

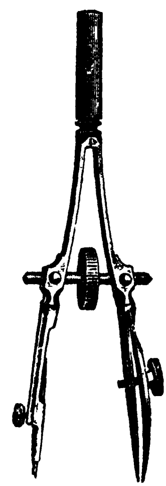


FIG. 37.

comes midway between the extreme point of the needle and the shoulder of the needle, when pinched up between the fingers into contact. This instrument, as well as the compass and the bow pencil, is intended to be used with the needle point pushed home to the shoulder in the paper.

48. Use of Drawing Pens.—By applying prepared India ink to the space **inside or between the two blades**, and adjusting their

width apart to the width of the line desired, a very sharp, accurate, and uniform line is produced, suited to the precise nature of mechanical drawing. The quill in the stopper of the ink bottle is provided so that its tip, with ink adhering, may be touched to the blades, inserting it in the crack between them, some distance above the points. The ink will, of itself, run to the end where the blades are nearest to each other. **Only the extreme 1/4″ of the pen should be filled with ink, and none whatever should be allowed to get on the outsides of the blades.** This rule is of vital importance. If it is broken, good ink work is impossible.

The pen is never used with the two points so screwed up that they touch each other. There must always be some gap between them, if only the thousandth part of an inch. Paper, if examined under a microscope of sufficiently high power, is seen to be, like felt, a mass of entwined and matted hairs. These hairs must have room to pass between the blades, otherwise upstanding hairs will catch in the blades, tear loose, and soon the pen will be drawing a line with a miniature mop of hairs on its end. It will become a brush, and the accuracy of the line will be lost.

49. Adjustment of Pens for Width of Line.—The blades of the pen are not entirely sharp. They are flattened, say the thousandth part of an inch, enough to keep them from cutting the paper. In theory the minimum line is the width of the space between blades plus the flattening of each blade. We judge this minimum to be about three thousandths of an inch, 0″.003. From this size up, lines may be drawn. Above 1/32″ lines cannot be made in one ruling, but must be built up by more than one stroke. There is very little use for built up lines in practice.

Between the limits of 0″.003 and 1/32″ the width of the line is entirely controlled by the thumb screw. Three specified widths are used for the standard drawings of the Navy Department, namely, five, fifteen and twenty-five thousandths of an inch, or in figures, 0″.005, 0″.015, and 0″.025. They correspond to "imaginary lines," "real edges," and "real edges, shaded." The present aim is to show how to produce these sizes at will without measurement and with sufficient accuracy for all practical purposes.

These sizes will be regularly referred to in this textbook as "fine lines," "standard lines," and "shade lines."

An intermediate size, 0″.01 thick, has been authorized recently for special use. It is called "medium."

We take up now the **coarse adjustment of the pen for fine lines.** With the pen empty and perfectly clean hold it before the strong

FIG. 38.

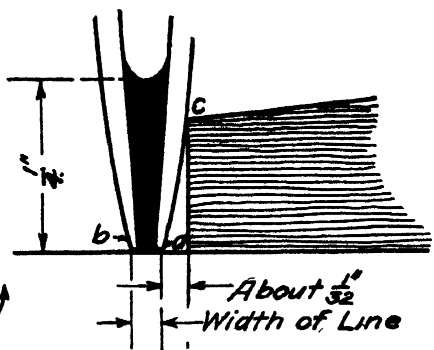


FIG. 39.

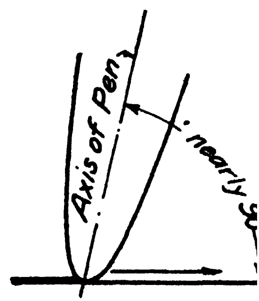


FIG. 40.

light of a window and screw the nibs together until only a very small opening between them can be seen. This is a rough adjustment only.

Another way to make the rough adjustment is to have the pen grip the erasing shield as in Fig. 38 and unscrew until the shield drops out slowly when swung from side to side.

Now fill the drawing pen with ink. Hold it point down. Touch the quill of the ink bottle stopper to the space between points and

allow about $\frac{1}{4}''$ of the pen to be filled with ink, no more. No ink must be allowed on the outside, especially at *a* or *b* of Fig. 39, and any which gets on by accident must be wiped off with a cloth at once. The ink used is that called "India Ink."

50. How to Hold the Pen.—With the scratch paper on the drawing board and the T-square in place we are ready to draw horizontal lines. Open the right hand, palm up, and place the pen across the ends of the first and second fingers at about 45° with the axis of the hand, as in Fig. 41. The tips of the fingers are in

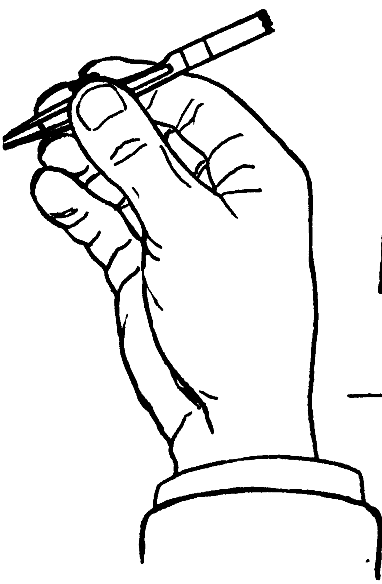


FIG. 41.

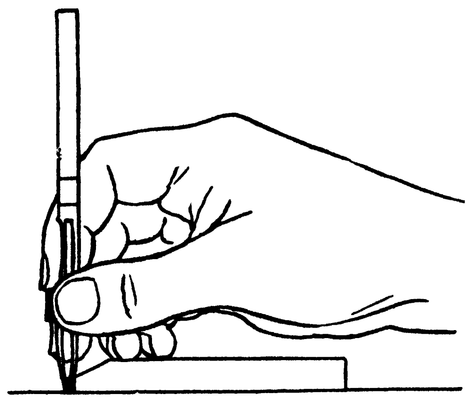


FIG. 42.

the crack between the blades, one below and one above the thumb screw. Next place the thumb above the pen, about on top of the thumb screw. With this light grip between the thumb and two fingers, raise the hand and put the pen in a position *vertical to the paper,* bending the third and fourth fingers underneath, as in Fig. 42. Bring the point *C* to contact with the straight edge, as in Fig. 39, and slope the pen slightly in the direction of motion, as

in Fig. 40. In this case incline to the right, and draw a length of horizontal line. In doing this the hand slides on the T-square and rests on the tips of the third and fourth fingers.

51. Accurate Adjustment of the Pen, (1) For Fine Lines, 0″.005 Thick.—Draw a number of lines on a piece of scratch drawing paper, so placed that they run off the edge of the paper. Pick up the paper and lay it on page 36 of this book and compare with line 11 of Fig. 44. If not a perfect match, adjust the screw, opening or closing the nibs, until the lines exactly match. With a pencil, preferably a colored pencil, mark the line *a,* Fig. 43-1, down the center line of the pen point, and the radius *cf,* on the head of the adjusting screw in line with *a.* Hereafter when *f* is lined up with *a* the pen will draw a correct fine line.

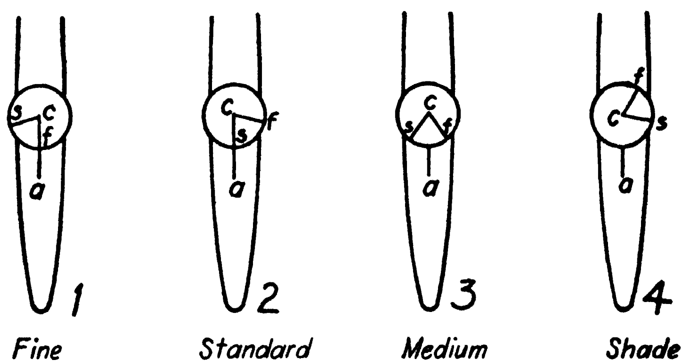


FIG. 43.

(2) Accurate Adjustment for Standard Lines, 0″015 Thick.—Turn screw about 90° to the left and repeat the former process of trial and comparison until a pen setting is found to produce lines which match line 1 of page 36. Mark the new position of the adjusting screw by a new pencil mark, *cs,* in line with *a,* Fig. 43-2. As drawing instruments now available are not uniform the angle *fcs* may be anywhere from 60° to 120°.

52. Comparison of Setting of All the Pens.—After drawing enough lines with the right line pen to be satisfied that it is acting

in its designed manner, and is producing uniform and sharp lines, take up the compass pen point. Adjust it in the same way, and rule with it, first without putting it in the compass, but guiding it against the blade of the T-square like the right line pen. Rule these lines near the former lines, and by tilting the T-square, make some cross the former lines in order to make a close comparison. Practice with the compass pen in the compass making large circles also.

Finally adjust and fill the bow pen and draw fine and standard lines crossing those already drawn and running over the edge of the scratch paper. When all pens draw lines matching lines 11 and 1 on page 36, and have pencil marks *cf* and *cs* on them, it will not matter if the angle *fcs* differs pen from pen. The lines must not differ. It is more important that pens draw alike than that the lines measure exactly 0″.005 and 0″.015.

After the pens have been used several weeks and the adjustments have been rechecked, when so directed by your instructor, mark the pens permanently by *"scribe marks"* (scratches made by the point of a knife) to replace the temporary pencil marks. Mark *a* may refuse to "take" but is easily imagined.

53. Adjustment of Pens for Medium and Shade Lines.—Medium lines are used in crowded spaces where standard lines might run together or make too black an appearance. They are in size midway between fine and standard lines. For a proper setting make the mark *a* fall midway between *f* and *s* as in Fig. 43-3.

A shade line is as much wider than a standard line as a standard line is than a fine line. In Fig. 43-4 another turn of about 90°, making the angle *acs* equal *scf*, Fig. 43-4, adds this 0″01 and produces the shade line, line 15, page 36.

54. Drawing Ink Lines over Pencil Lines.—Comparing Fig. 39, page 32, with Fig. 31, page 24, we see that the pen keeps much farther away from the guiding edge than the pencil does. Because of this, ink work cannot be accurate unless done over pencil work, and in setting guiding edges for inking this increased distance must be allowed for.

A pen must be readjusted if it has been resharpened, after wear or breakage, or even if the adjusting screw has been removed and

replaced. In such cases it must be set anew. The old scratch mark on the screw head can be ground off by rubbing against the oil stone or the pencil sharpening pad.

THE DRAFTSMAN'S

"ALPHABET OF LINES"

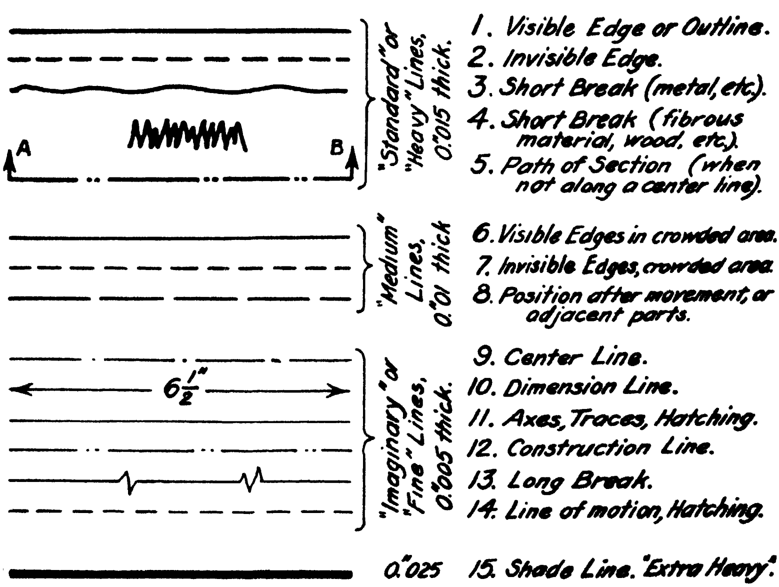


FIG. 44.

55. The Alphabet of Lines.—The lines regularly used have been standardized as shown in Fig. 44. Every draftsman must become familiar with them and should use them in spite of seeing variations on older drawings. Nos. 1 to 5 are for lines representing edges of real objects. Nos. 9 to 14 are for lines representing mental concepts, not real edges; 6, 7, 8 and 15 are modifications whose purpose will be explained later.

56. Faulty Ink Lines.—In Fig. 45 are shown faulty ink lines, and the cause of the defects to assist the beginner to recognize his faults. In the *top line* the pen has been so held that the pressure of the thumb is concentrated on one blade and that of the first and second fingers on the other. Thus any variation in the pressure causes a variation in the width of line drawn. In the correct holding of the pen, Fig. 42, the pressure is on the edges of the blades, not their backs, and considerable variation in pressure causes no movement of the blades. In the *second line* the attempt was made to draw too close to the edge of the T-square, with the result that some dust lodging there caused the ink to flow under the T-square. The same effect is produced by moving the T-square up, touching

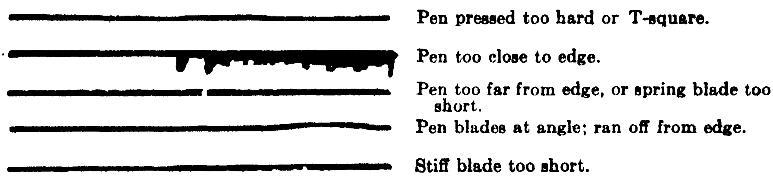


FIG. 45.

the wet line, and then down, drawing the ink with it. In the *third line* the pen was slanted out, drawing a line too far from the T-square. The outer blade did not touch the paper, leaving the upper edge of the line poorly defined. The same result is produced if the pen is poorly sharpened, the outer or spring blade being shorter than the inner or stiff blade. In the *fourth line* the pen blades were not kept parallel to the T-square, but inclined up to the right slightly. As a consequence they ran off the track for a space. The *fifth line* was produced by a pen whose stiff blade was too short and therefore hardly touched the paper.

57. Method of Inking Extra Wide Lines.—In inking lines too wide to be drawn with one sweep of the right line pen, several rulings of the pen must be used. It is not well to rule these new lines in contact with the wet ink of the old, or the ink will build up too high a mound, which will take a long time to dry and will be apt to

cake and crack off in the end. Fig. 46 indicates the difficulty. In 1 a single line has been ruled about half the width of the desired line. In 2, the second ruling is in contact with the wet ink of the first line. The pen gets wetted on the outside, the ink flows too freely and the final result, No. 3, is a mound of ink standing over the line of the desired width.

The correct procedure is shown by the series, 4, 5 and 6. The second ruling should **not be in contact** with the first. Leave a small gap as shown in No. 4. **With the ruling pen dry**, but while the two ink lines are still wet, rule over the crack between them as

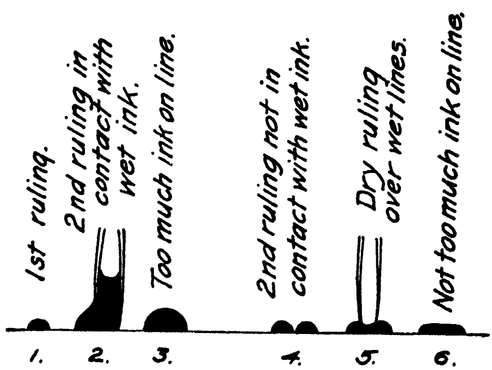


FIG. 46.

shown in 5. The ink will then flow in and cover up the crack and the wide line will be covered with ink in the condition of No. 6, instead of No. 3. This will dry rapidly; there is little risk of smearing; and as it is not heavily caked when dry, it will not peel off.

This method may be applied to lines which require several rulings to get the desired width. Each ruling should hardly exceed $1/32''$ in width. Wide lines, however, are not much used in practical drawing work.

58. Rules for Inking.—Much faulty work will be avoided and much time saved if the student will make the strict observance of the following rules for inking habitual.

1. *Never Fill More Than 1/4" of Pen.*—More ink will cause the line to be wider than its setting at start, or it will cause bulbs of ink at the ends.

2. *Wipe All Traces of Ink From the Outsides of the Blades.*

3. *Never Lay a Pen Down Full of Ink; Wipe it Out.*—When you use the pen again the ink will surely be spoiled by the thickening due to evaporation. Form a habit of wiping out the ink before laying the pen aside and much annoyance will be saved.

4. *Never Put New Ink on Top of Old.*—If you desire to refill the pen before it has run dry, it must be that the ink in it has become too thick by evaporation. It is, therefore, spoiled ink and should not be allowed to contaminate the new ink. Form the habit of wiping out old ink.

5. *If Ink Refuses to Flow, Pinch the Blades Together.*—This may loosen a clot forming at the end. If it still refuses to flow, the ink is too sluggish. Clean it out.

6. *Never Re-ink a Line in the Reverse Direction.*

7. *Never Erase an Ink Line until it is "Bone Dry."*

8. *Once a Day Thoroughly Clean the Pen with Water.*—Open the pen completely. Soak each blade in water. There should be in the ink drawer of each desk an old ink bottle which has been cleaned out and filled with water for this very purpose. With an ink rag give a thorough scrubbing to the insides of the blades, removing all traces of old crusted ink. If this crust gets too thick it will peel off in flakes and form lumps in the fresh ink, causing very ugly blots when the lumps try to pass through the narrow opening between the blades.

59. Ink Rag.—The best way to use an ink rag is to fold it across, then fold at right angles, leaving a corner projecting. Insert this corner between the blades well up above the points. Draw it through part way. Twist the pen, revolving it on its axis at least one complete revolution. The part of the rag which was not pulled through between the blades will now be wrapped around them on the outside. Now pull the rag off the end of the pen. The corner will pull through the blades and the rest of the rag will wipe off the outside thoroughly in one operation. The whole act requires only a moment.

60. Pen Holder and Pen Points.—These are included in the list here and they are part of the midshipman's equipment. The use of the ball pointed pens for lettering is explained in Chapter VI, which is devoted to that subject. The sharp pointed pens are used for forming arrow heads and for small repairs to ink lines, such as for filling small accidental gaps at ends of lines.

61. Arkansas Oil Stone.—This stone is a hard, fine-grained stone such as that used by carpenters for sharpening chisels and planes. It is used for sharpening drawing pens, steel erasers and pocket knives, and for such light work a thorough wetting with water, instead of oil, is sufficient. Fig. 21 on page 16 illustrates the use of the stone to reduce the size of needle points.

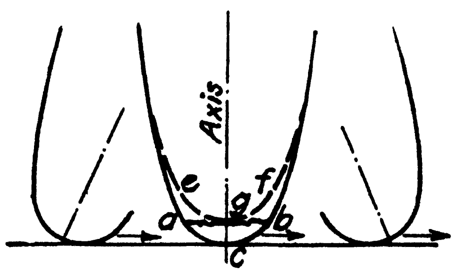


FIG. 47.

62. How to Sharpen a Broken Drawing Pen.—Pens when new are presumably correctly sharpened. A drop on the floor, however, may snap one or both blades, or wear, itself, may so dull a pen that it becomes necessary to resharpen. This is not difficult if one realizes the nature of the steps to the process and follows out each step carefully. The description which follows is given for the right line pen, assuming that one blade has been broken flat across the end, the worst case we have.

The first step is to grind a new contour within the line of the break. In Fig. 47 the near blade is broken along the line *agb*. The far blade has its original contour *acb*. It is desired to grind a new contour *egf*, within the broken blade. To accomplish this the pen is screwed up until the two blades just touch and is then put in contact with the wet stone and moved in the direction of the blades

as in drawing but with a rocking motion, back and forth, with its axis leaning first far forward, then standing straight, and then leaning far back as shown. More metal must be removed at *a* and *b* than at *c* since at *c* there is but one thickness of metal to remove.

The two blades are now alike in contour but very dull. The next step is to sharpen each blade without altering the new contour. For this separate the blades widely. Choosing one blade to sharpen first lay the outside of this blade against the stone, at a very sharp angle with it. Move it now in a "figure of eight" path as indicated in Fig. 48. The pen should be rocked from side to side and most of the grinding done when the steel moves against the cutting edge. This will tend to sharpen the entire contour from *e* to *f*, but all parts will not necessarily come to a sharp edge at the same moment.

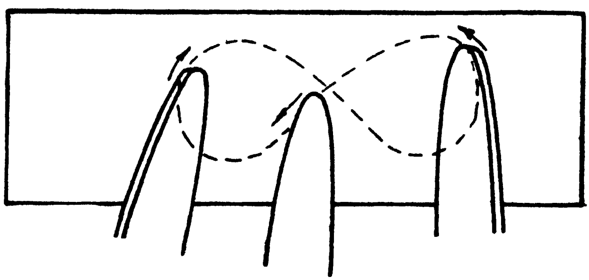


FIG. 48.

The difficulty now is to avoid over-sharpening any one place for that would alter the contour and make the two blades unlike. The blade is tested at frequent intervals by drawing it over paper in the manner of Fig. 47, and the parts of the blade which cut the paper are noted. As soon as any one spot is sharp enough to cut the grinding motion is modified to avoid further grinding of that spot. If successful the whole contour *egf* is brought to sharpness without reducing any of it to smaller dimensions. Treat the other blade in the same way.

The blades are now alike but too sharp. The final step is to dull them by a very slight amount, by means of a very gentle stroke. The blades are tried again on paper until certain that each blade is just dull enough not to cut during use.

The index marks on screw head (see Fig. 43, page 34) must be ground off and new marks put on, after a new adjustment, whenever the pen is sharpened.

63. Sharpening a Pen Dull from Wear.—A far less radical method often suffices for a pen which is but slightly dulled. In such a case it is assumed that the contour is correct, and a slight grinding given to each blade. In fact this grinding may be given by the sharpening pad, using the crocus cloth side, and making the strokes more from the edge than towards it.

64. Erasing Shield.—This is a thin sheet of steel or of brass, nickel-plated (see Fig. 49). It is perforated with openings which correspond to the ordinary lines of drawings. The shield is used

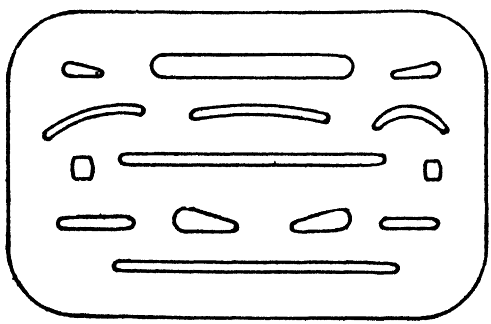


FIG. 49.

to protect good work while erasing adjacent bad lines. The openings are used to expose just the line or part of line which needs erasure, and the rubber eraser is used over it.

If the ordinary emerald or ruby rubber is not effective, the gritty "ink eraser" or "typewriter eraser" is used.

The shield is about three one-thousandths of an inch thick, 0.″003 Its use as a feeling piece for setting pens to draw the standard fine line has been explained in Art 49, page 32, and illustrated by Fig. 38.

65. Steel Ink Eraser or Knife.—This is a steel blade fitted to a wooden handle. The sharpened edge is the full length of the blade on one side, and a third of the length on the other, as seen in Fig. 50. Its description is included here among other erasers because of its name, but its use for erasure is a very minor one. The scratching of the surface of the paper as ordinarily practised for desk work is but little done by draftsmen. The uses of the knife are these:

FIG. 50.

1. *To Cut off Waste Margins of Drawing Sheets.*—This may be done against a guiding edge, but, as it puts the edge in great danger of being cut, **the working edge of the T-square must not be used.** The lower edge may be used. A better procedure is to follow the

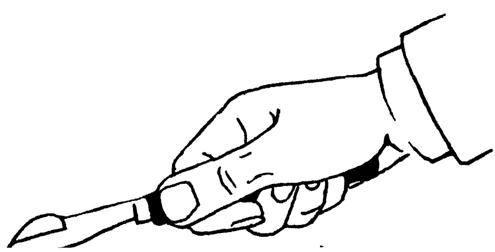


FIG. 51.

pencil cutting lines with the knife with no other guide than the knife blade's own tendency to travel in a straight line. To get this tendency at its best, hold the knife "underhand," as shown in Fig. 51.

2. *To Cut the Wood, Not the Graphite, of Lead Pencils.*

3. *To Trim off Excess Ends of Ink Lines.*—This is done by two sharp cuts. Find a part of the edge which cuts very freely.

In Fig. 52, where the thickness of the paper and of the ink line have been greatly enlarged, the directions of the cuts needed are clearly shown.

4. *To Scratch up and Loosen by Very Light Strokes the Crusted Top of a Heavy Ink Line.*—This erasing of the ordinary kind is done by draftsmen only to very heavy lines, as a beginning, so that the other rubbers may take hold. It must be done with a light touch only. If too much pressure is used, the cutting edge may vibrate in such a way that minute perpendicular cuts are inflicted on the paper. These cuts will catch the ink if any endeavor is made to work over the erasure, and the last state of the drawing will be far worse than the first. Great caution is therefore necessary.

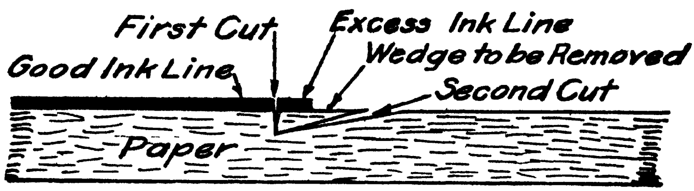


FIG. 52.

66. Polishing Erasures.—A bad erasure may need to be polished before new work is put over it. Professional draftsmen often have an agate stone mounted on a handle for polishing. The finger nail is a fair substitute for the agate. Turn the hand over and rub the surface with the back of the nail of the little finger until any loose fibers are pressed back even with the surface.

CHAPTER IV

SET OF INSTRUMENTS. THE MEASURING INSTRUMENTS

67. The Measuring Instruments.—These consist of the dividers, spacer, and scale.

68. The Dividers.—This instrument is a simple variety of compass, adapted not to drawing circles but to stepping off distances accurately. From its origin as a compass it is still occasionally called a compass. We see from Fig. 53, that it has sharp pointed legs without joints.

The thumb screw on the right leg in Fig. 53 is not the mark of a slip joint, like that of the compass, but is for a very different purpose. It is the screw for the "hair spring adjustment." The steel point of the left leg is brazed to the German silver shank. The steel point of the right leg has a long spring piece extending it above the apparent line of junction. This piece is set in a recess in the German silver shank and is invisible when the instrument is closed. Open the instrument and examine the inner surface of the leg. The spring will be seen, extending well up within the shank, and secured to it by a screw near the head of the leg. The thumb screw, in the position illustrated in Fig. 53, is screwed up tight. Release it and the whole steel point will move, springing away from the shank, by reason of the initial curve given to the spring in manufacture. Fig. 54 shows the spring point dismounted from the dividers. Note particularly that the side view shows that the spring is not perfectly straight when in the unstrained position.

In using the instrument the adjustment by springing the legs apart at the head of the dividers is the *coarse* adjustment. The thumb screw permits a very delicate movement of one point for the *fine* adjustment. This hair spring for the fine adjustment may be applied to the compass, but for the average draftsman it is not considered necessary. The dividers require it, for they are used for work which requires the highest degree of precision in drawing.

Extreme accuracy is the rôle of the dividers, and it is folly to attempt to use them, as many beginners do, without using the hair spring adjustment.

69. Bow Spacer.—This instrument, shown in Fig. 55, is similar to the other bow instruments, with the exception that the legs terminate in sharp points like the dividers. They are convenient

FIG. 53.

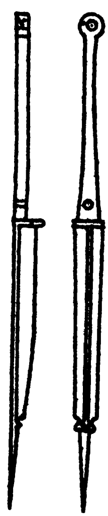


FIG. 54.

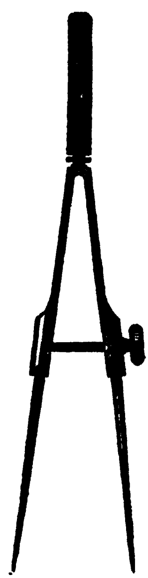


FIG. 55.

FIG. 56.

for small distances, for which they are better suited than the dividers. The coarse or quick adjustment is made by pinching the legs together and rapidly spinning the nut along its screw, as described in Art. 25 for the bow pencil. Fine adjustment is made by

slowly turning the thumb screw under the natural friction due to the pressure of the spring bow.

The form of bow spacer with central thumb screw is not in favor, even with experts.

70. Bisection by Dividers or Spacers.—The typical use of the dividers is well illustrated by the process of bisecting a line, as is illustrated in Fig. 57. It is a "trial and error" method. The dividers are first opened roughly at a guess to one-half the line.

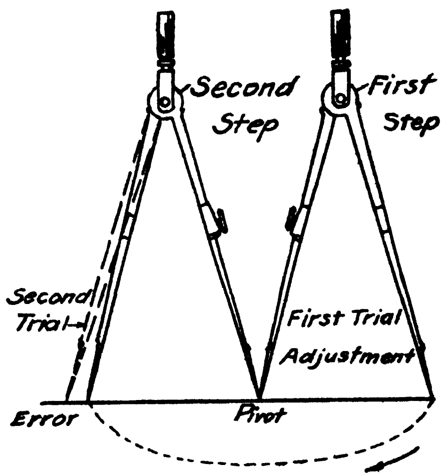


FIG. 57.

This distance is stepped off on the line, and the two applications of it presumably leave an error of excess or deficiency.

Leave that leg, which has acted as a pivot in swinging from the first step to the second, in contact with the paper and raise the other slightly. Now alter the adjustment by that distance which the eye judges to be one-half the error, and repeat the process of stepping off along the line. On the third correction use the hair spring adjustment if you have not already done so. It is only a question of time when the error is so reduced as to be negligible. In dividing lines to thirds, the setting is modified each time by one-third the error observed, and so on. Fig. 57 illustrates well two

of the less usual lines in the "alphabet." The swinging of one leg of the dividers about the other as a pivot is indicated by a fine line of short dashes like line 14 in Fig. 44, page 36. The position of the leg of the dividers for the second trial illustrates the "position after movement," or line 8 of Fig. 44. The width was reduced as Fig. 57 has been reduced in printing.

71. Proportional Dividers.—This instrument is not part of the equipment of midshipmen, but it is one every draftsman should know. It is part of the equipment of many drafting rooms, and is valuable for special purposes, as for enlarging or diminishing drawings, or for comparing maps on different scales. As seen in Fig. 56, it is a double ended pair of dividers with the joint movable so that it may be set at any point along the two legs. One end is a diminished copy of the other end of the instrument, and the ratio of the sizes is controlled by the location of the pivot. In the illustration the pivot is so set that the large end measures a distance a little over three times that measured by the small end.

72. The Triangular Scale.—This scale is of box wood, and it measures $12\frac{3}{4}''$, over all, the ruled portion being exactly $12''$ long. It is an instrument of delicacy and precision, and should be protected from rough usage and from unnecessary wear or injury. It has a special place in the box designed to hold it.

The scale is not to be used as a straight edge or rule. It does not guide a pencil or pen. It is used by applying its marked edges to lines on a drawing, or by applying the points of the dividers or of the compass to it.

The triangular form allows the combination of many separate scales in one instrument. Professional draftsmen often prefer sets of flat scales, each with one or two scales only on it. The combined instrument is desirable for general use, because it is compact and no part can be lost or mislaid.

73. Graduation of the Full Size Scale; Inches and Eighths.—Of the six graduated edges on the scale, two are for making drawings to full size. One of these is graduated to "inches and eighths" as the expression is. It is the one marked "32" and inches are subdivided by continual bisection, to halves, quarters, eighths, six-

teenths and finally thirty-seconds. The lines which mark the inches are the longest, those marking the halves the next, and so on. The inch marks themselves are recorded by figures, from 0 to 12, the figures being printed in the semicircular groove adjacent to the mark. Fig. 58 is a full size drawing of the scale with a large portion of it broken out and the ends closed in to shorten it. Between the breaks a cross section of the wood is drawn, showing the three grooves and the six flats for the rulings. It is a general principle in the use of scales that the eye can be trusted for one more subdivision than the graduations give. This full size scale can therefore be used to measure sixty-fourths of an inch. For all ordinary work in machinery this is considered a sufficient degree of accuracy.

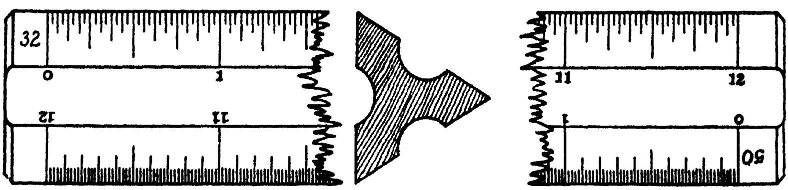


FIG. 58.

In this course, unless otherwise directed, one thirty-second of an inch is considered the degree of accuracy required, including that for diameters of circles. The sixty-fourth is required only for the radii of circles unless other instructions are given.

The student should realize that in Fig. 58 the scale is being held up before the eyes for examination. To use it on a drawing put it flat on the paper with the edge having the desired graduations away from the body. The draftsman habitually looks over the scale from above.

74. Graduation of the Full Size Scale; Decimal.—For some classes of accurate work the decimal subdivision of the inch is usual. Although fits of journals in their bearings are measured in thousandths and ten-thousandths of an inch, no attempt is made to represent such minute distances on a drawing. Dimension figures, instead, are relied upon to record them.

It is possible, however, to work to the hundredth part of an inch on the drawing, and the scale marked 50 is intended for this work. Fig. 58 viewed from the top of the page shows this scale well.

The longest marks on this scale are inch marks, as indicated by the figures from 0 to 12, printed in the groove. The half inches are marked by lines of the next length, and these spaces are divided by the lines of the next smaller length, into fifths. These are of course tenths of an inch. These tenths are subdivided again into fifths, or fiftieths of an inch, by means of the shortest lines on the scale. The accuracy of the eye for bisection makes this scale available for hundredths. For example, to lay off a distance of 3″.47 we begin at the end where we find the 0 mark, count off the inches, then count off four tenths, then seven hundredths, counting at first by pairs, as "two," "four," "six," and finally subdividing the next space by eye for the odd hundredth.

75. Graduations for Reduced Scales in Pairs; Open Graduations. —The four remaining edges to the triangular scale are graduated for use when making drawings to reduced sizes, such as quarter size, one-eighth size, one-twelfth size, etc. A reduced size is regularly quoted in the drawing room by the number of inches which represents one foot. Thus the quarter size is derived by making one quarter of a foot represent a foot. It is spoken of as the 3″ scale, or the scale of 3″ to the foot. On the triangular scale a space of three inches is subdivided as if it were a foot and the figure 3 at the extreme end of one of the graduated spaces marks this scale.

At the opposite end of the edge on which the 3 is stamped will be found the figures 1½, marking a scale in which 1½″ represents a foot. This is the one-eighth scale. Between the closely graduated spaces at the ends, there is a wide space with a few marks only. This space is used with both scales, but for distances representing feet, not inches. These are called open graduations. To make the open graduation apply to both scales, one scale is always the double of the other.

On the triangular scale furnished to midshipmen the reduced scales are paired as follows, 3″ and 1½″, ¾″ and ⅜″, 4″ and 2″, and 1″ and ½″.

Many other reduced scales are possible. The selection here covers the scales usual for machine work. Architects use smaller scales freely, such as ¼″ and ⅛″, $^3/_{16}$″ and $^3/_{32}$″.

76. Method of Marking Graduations of Reduced Scales.—An explanation of one pair of these will cover the principles of them all.

Let us select the 1″ and ½″ scales for explanation. Hold the scale horizontally with the edge up which shows the figure 1 on one end and the ½ at the other.

Fig. 59 represents the scale with a large part of the open graduations in the middle removed and the ends closed up. In the drawing the scale is only 4″ long, while in reality it is 12″ long.

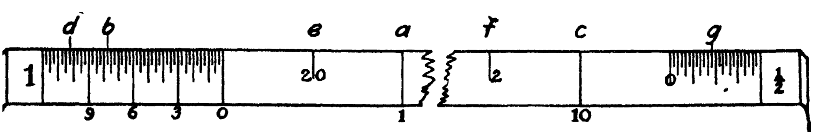


FIG. 59.

The 1″ space at the left is graduated to represent 12″. From the zero mark, printed in the semicircular groove, one can count 3, 6, or 9 inches by the figures, also printed in the groove. For intermediate inches one counts by means of the lines which are next in length to those for the 3″ spaces. To subdivide the individual inches into halves and quarters shorter and yet shorter lines are provided. The scale then reads to quarter inches, and can be used by visual subdivision to eighths. To the right of the zero mark the open graduations give feet. These are long lines and the number is printed in the groove, from 1 to 10. In some scales these numbers are printed *near* the groove but not *in* it. The shorter marks in the open graduations (of which we see in Fig. 59 one marked 20 and one marked 2), do not refer to this scale at all.

The use of the scale for a distance involving both feet and inches can be illustrated by the points above the scale designated by letters. From *a* to *b* measures 1 foot (by count to the right from the zero mark), and 7¾″ (by count to the left from the zero mark), the first

6″ by the figure, and then 1″ and the fractions. This distance is usually called 19¾″ by mechanics, a customary thing for distances less than 2 feet. From *c* to *d* measures 10 feet and 10¼″.

For the ½″ scale we find the half-inch space at the right graduated as if 12″. There is a zero mark but no mark for 3, 6 or 9 inches. There are long marks for them, however, though they do not reach entirely across the flat of the scale to the groove. Shorter inch marks, and still shorter half-inch marks complete the graduation of this scale. To the left of the zero mark are open gradua-

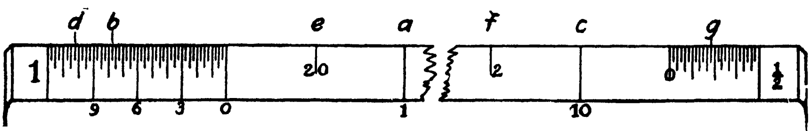


FIG. 59.

tions, every second one of which is short and has a number, 2, 4, 6, etc., up to 20. Fig. 59 shows only the 2 and the 20. The long marks, already used for the feet of the 1″ scale, must be counted for the odd numbers in reckoning feet for the ½″ scale. Note that the zero of this scale and the even figures which apply to it, are all printed on the *flat* of the scale itself, never in the *groove*. It is by

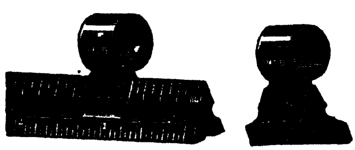


FIG. 60.

this distinction that the figuring for the two scales is kept apart. As an illustration of the use of the half-inch scale we may note that the distance *f* to *g* reads 2 feet 5½″. The distance *e* to *g* represents 20 feet 5½″, while *c* to *g* represents 17½″ and *a* to *g* represents 19 feet 5½″.

The right half of Fig. 60 shows a "scale guard," a metal clip to act as a handle for the scale. It is a convenient article but not a necessary one. The left half of Fig. 60 shows it clipped to a metal

scale with white graduations. The edge in contact with the paper, having inch marks, 1 and 2, showing, is in use and the man using it should be behind the scale as here seen. The other ruled edge of the scale which makes proper contact with the paper, but is turned away from us in Fig. 60, is partly obscured by the wide metal plate on the far side of the clip. This is a reminder to the user not to change scale inadvertently.

77. Pricker.—This instrument is a convenient one but not a necessary one. It has been included in the midshipmen's set at times and omitted at others. It is simply a needle point conve-

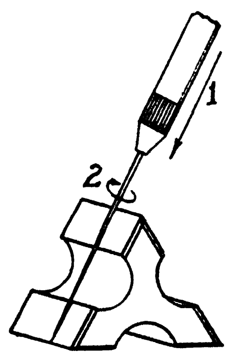


FIG. 61.

niently mounted, with an ebony, ivory, or aluminum handle. The best form of pricker is a handle with a tip which takes a piece broken from any sewing needle of the right size. A pencil sharpened to a long cone point makes a satisfactory pricker. The point must feel as sharp as a needle when touched to the back of the hand.

78. How to Take Dimensions from the Scale.—To transfer a point from the edge of the scale to the paper we make use of the graduations to obtain an accuracy greater than that of the unaided eye. The graduations are really grooves, partly filled with black paint. A long, sharp cone, either a pencil so sharpened or a pricker, when held almost in the exact line of one of the marks of the graduations as in Fig. 61, will follow the line and slide down the slight groove to the paper. To make a mark there a twirl is given

to the pencil. This can be done with little pressure on the point and a black mark results without breaking the delicate cone point. If a metal point is used the twirl will make a minute prick mark, quite visible yet much smaller than the prick mark made by exerting pressure only. In this case the needle bores its way in. If the point is forced in by pressure alone, the paper resists at first but finally yields suddenly, and the prick mark resulting may be larger than intended.

Try this method with a carefully sharpened cone-pointed pencil. When properly handled the accuracy is almost that of the scale itself. An expert can easily lay off thirty-seconds of an inch by touch with the eyes shut.

The draftsman habitually looks over the top of his triangular scale to that edge, in contact with the paper, which is away from his own body. Thus in Fig. 61 the draftsman is supposedly to the right and is looking down along the pricker there shown.

79. How to Scale Drawings to Find the Dimensions.—The reverse operation to that of transferring dimension from the scale to the paper is that of applying the scale to read dimensions from drawings already made. The scale to be used must of course be known.

A distance to be scaled is along a line and is generally defined by cross lines at the end. In fact it is usually the perpendicular distance between parallel lines which is the one to be scaled.

The usual procedure when using a reduced scale is to **make one of the foot marks in the open graduations coincide with one of the parallel lines, and to make the other parallel line fall somewhere within the close graduations of the scale in question.** Under these conditions, feet, inches and fractions of an inch can all be read with one placing of triangular scale.

Figs. 62, 63 and 64 illustrate measuring the horizontal distances between various parallel vertical lines with the $1\frac{1}{2}''$ and $3''$ scales. All other graduated scales have been omitted purposely.

The drawings are practically to scale and the student will do well to get out his own scale and place it over each figure in turn as he considers it.

In Fig. 62 the distance between the vertical lines A and B is be-

ing measured by the $1\frac{1}{2}''$ scale, and is supposedly part of a drawing made one-eighth size. The figure $1\frac{1}{2}$ to the extreme left is the identifying mark of the scale required. The figures for inches, 9, 6, 3, and 0, are **on the "flat"** of the edge and the figure 2 at the extreme right on the flat, **is in line with them, thus indicating that it belongs to the same scale.** This 2, being placed to coincide with line B, line A falls within the close graduation at the left. We read now from right to left, 2′, as explained; then 7″, because A is beyond the next long mark beyond the 6″ mark; then $\frac{3}{4}''$, by the fractional distance from the 7″ towards the 8″ mark. We thus arrive at $2'–7\frac{3}{4}''$ for the distance between the lines A and B.

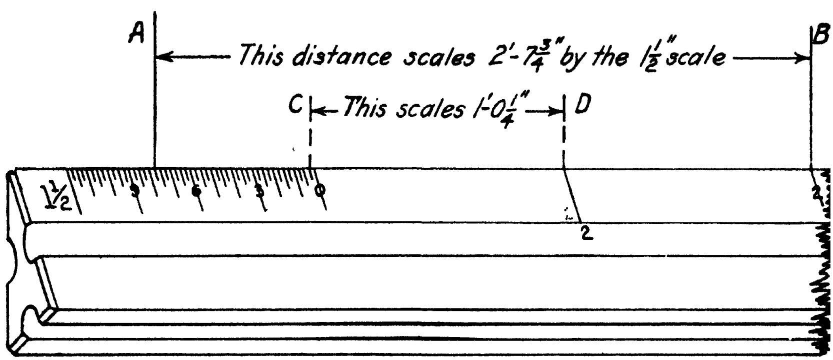


FIG. 62

There is another figure 2 printed in the groove, or, in some scales, near the groove where the dotted figure 2 is shown. This *figure,* because not in line with the 9, 6, 3, 0 of the scale does not belong to the $1\frac{1}{2}''$ scale. The *line* does belong however, and, because half way between the 0 and the true 2 foot mark is the 1 foot line. Thus in measuring the distance between the broken lines C and D this 1 foot mark, coinciding with D, enables us to read $1'–0\frac{1}{4}''$ for this dimension.

Let us turn now to the right end of the same flat, where the figure 3 indicates that it is the scale where 3″ equals 1 foot.

On the next page Fig. 63 shows the close graduations. The scale is there placed to measure a distance EF, the zero mark matching the line E, and the line F falling within the close graduations of the scale.

The 0, 3, 6 and 9 **printed in the groove** (or near the groove where the dotted figures are), enable us to read this dimension as over 8″ and under 9″, reading from left to right in this case.

Beyond the 8″ mark we note five of the smallest spaces *plus one half*. We change the five-and-one-half eighths to eleven sixteenths and so arrive at $8^{11}/_{16}$″ as the answer.

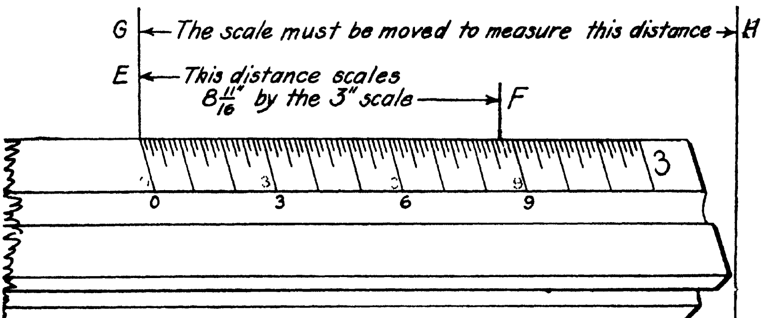


FIG. 63

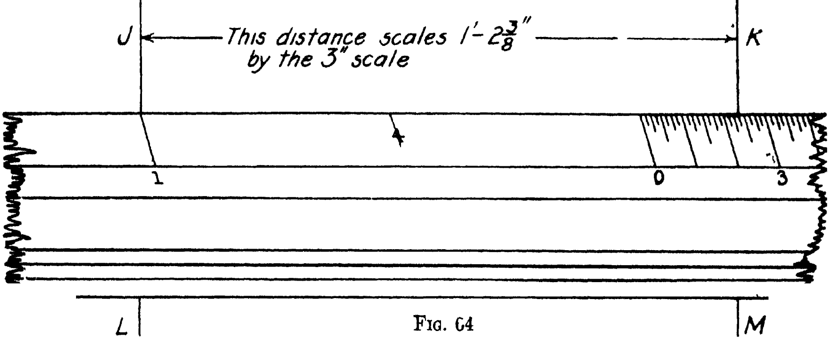


FIG. 64

A distance greater than one foot on this scale, such as GH, cannot be measured by the close graduations alone. The scale must be shifted to the right.

In Fig. 64 the line G has been carried down to J and L, and the line H to K and M. The scale is represented as having been shifted to the right until the line J coincides with the figure 1, **printed in the groove** which designates 1 foot. We now read JK to be 1′–2⅜″ long.

CHAPTER V

SET OF INSTRUMENTS. THE FLAT INSTRUMENTS

80. The 45° Triangle.—Of the flat instruments for the drawing board, consisting of triangles, protractor and French or xylonite curves, the first to be considered is the 45° triangle. This instrument is made of xylonite, a variety of celluloid, and is transparent. Formerly wood and hard rubber were used, but the xylonite is best.

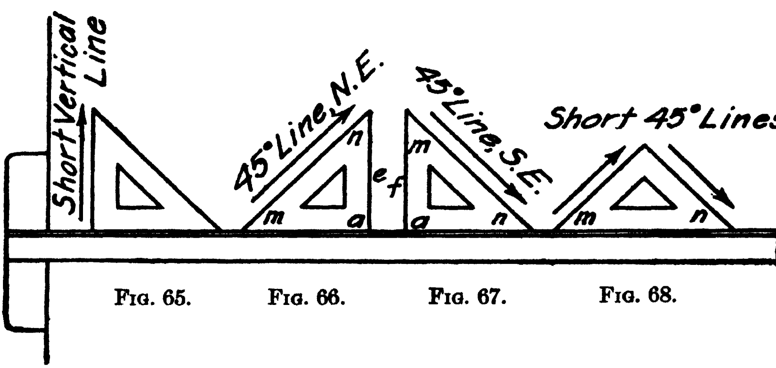


FIG. 65. FIG. 66. FIG. 67. FIG. 68.

The triangle is used in conjunction with the T-square for drawing vertical lines, or lines at 45° with the horizontal. This is the primary use for it, and in Figs. 65-68 it is shown in place, touching the blade of the T-square, and in the positions for drawing the lines specified. Fig. 68 shows a convenient position for drawing short 45° lines.

Accuracy in the use of the instrument requires that the T-square shall be held in contact with the working edge of the drawing board, while at the same time the triangle is held in contact with the working edge of the T-square, and is adjusted to the particular location for the required line. In adjusting the combination of

instruments, the T-square must be held by the left hand on the head, as shown in Fig. 5 of page 5, and at the same time the triangle fitted to its position and to the T-square by the right hand. When taking up pencil or pen to draw the line, the left hand must clamp both instruments in place. This is shown in Fig. 69.

The proper direction of motion for drawing these lines is shown by the arrows in Figs. 65-68. It is so chosen that the right elbow may move rather away from the body than towards it. If it should

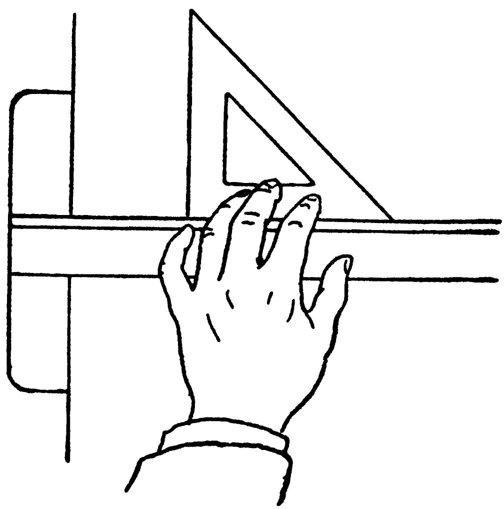


FIG. 69.

move towards it the action will be cramped by the striking of the elbow against the side of the body and the lead pencil may be tilted or joggled. Horizontal lines are always drawn from left to right for the same reason.

81. Testing the 45° Triangle.—The first test to give to the triangle is one for the accuracy of the *90° angle.* Put the triangle in the position of Fig. 66 and draw a vertical line along the edge, *e,* making an exception to the usual rule for drawing vertical lines. Turn the triangle about the corner, *a,* into the position of Fig. 67, and draw a vertical line almost touching the line already drawn.

Let the space between them be less than $\frac{1}{32}''$. Any lack of parallelism will be very apparent and will indicate a lack of accuracy in the 90° angle. This test depends for its validity, first, on the proper holding of the pencil during the drawing of the lines. The pencil must be kept perpendicular throughout its motion. The test depends, secondly, on the accuracy of the blade of the T-square. Try it at several places along the T-square to guard against false results from this cause.

To test the *45° angle,* draw a short vertical line with the tested 90° angle, as in Fig. 70. From any two points, *a* and *b,* draw along the T-square two horizontal lines, and, with the aid of the 45°

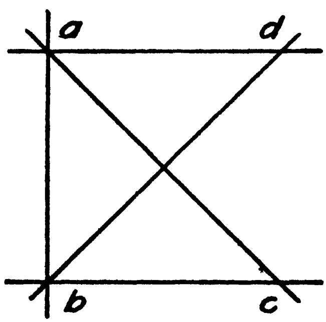


FIG. 70.

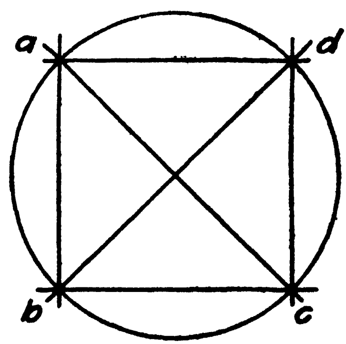


FIG. 71.

triangle, two 45° lines intersecting the horizontal lines at *c* and *d.* Do this with triangle in the position of Fig. 68, in preference to other positions, in order to be sure to use the two different angles, *m* and *n.* Finally draw a vertical line through *c.* It should check at *d.*

A variation of this test begins with a large, carefully drawn circle, as in Fig. 71. Pass two 45° diameters, using different angles, *m* and *n,* being careful that the lines pierce the center, the pencil feeling the needle mark at the center as it runs over it. Horizontal lines, drawn with the T-square, from *a* and *b,* should check at *d* and *c,* and vertical lines from *b* and *c* should check at *a* and *d.*

82. 60° Triangle.—This is also called a 30° triangle. Its angles are 90°, 60°, and 30°. It is designed for describing long vertical lines and lines at 60° and 30° from the horizontal, inclining to right or left. The longest edge is, of course, the hypotenuse, as is that of the 45° triangle, because opposite to the right angle.

The position shown in Fig. 72 is that for drawing long vertical lines. It is also that for one 60° line. Fig. 73 shows the position for the other 60° line, and the next two figures show the positions for the 30° lines. In the last position a short vertical line can be drawn. The position for long vertical lines is preferable for lines exceeding 5″ or 6″. With the triangle used in a midshipman's equipment, lines as long as 9″ can be drawn at one operation without piecing new lengths to old.

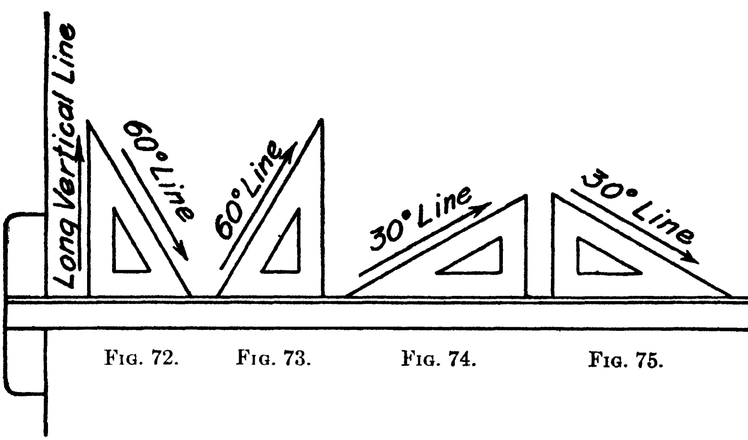


FIG. 72. FIG. 73. FIG. 74. FIG. 75.

83. Testing the 60° Triangle.—Test the *90° angle* exactly as that of the 45° triangle was tested, the first position of the triangle being that of Fig. 73, and the second that of Fig. 72. The vertical lines drawn must be very close together of course. To test the *60° angle,* draw inclined 60° lines, like those shown in Figs. 72 and 73. but with the second position closer to the first so that the lines intersect near the T-square. Now fit the 60° angle in the V notch formed, making sure that both edges can be made to coincide with the lines drawn.

If the 90° angle and the 60° angle are correct, the 30° one must necessarily be correct also.

84. Bent Points on Triangles.—The xylonite triangles, when once true, remain so with two exceptions. Occasionally a fall to the floor, hitting a point of a triangle, especially the 30° point, may result in curling it over as shown in Fig. 76. Such a point must be cut off with a sharp knife, or the projection, when resting in contact with the T-square, may spoil the accuracy of the angles. Many draftsmen cut off 1/8″ from each corner to prevent this possible defect. It is an accident which may long go unnoticed. The extreme points will never be missed. No draftsman ever attempts to construct an angle with one setting of the triangle, by drawing from two directions to a point.

The triangles are occasionally subject to warping. This defect

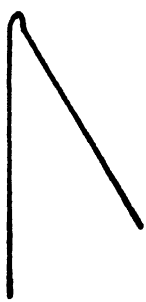


FIG. 76.

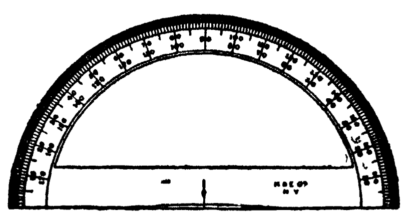


FIG. 77.

can be taken out by hand by bending warped triangles to the opposite curvature, or, in bad cases, by holding them to the opposite curvature by weights for a while.

85. Protractor.—The protractor, as used by midshipmen, is a small flat instrument in the form shown by Fig. 77. It may be made of transparent xylonite, steel, brass, or German silver.

Its function is to aid in laying off angles, and it is used generally against the T-square. It may be used by adjusting the bottom flat edge, the diameter of the semicircle, to a line with the mark at the middle at the point which it is desired shall be the vertex of the angle. The graduation figures read from either end, and the gradu-

ation lines show intervals of 10 degrees, degrees, and half degrees, according to length. The instrument may be read to quarter degrees.

In Fig. 78 two steps in laying off angles are shown, the protractor having most of its graduation omitted for simplicity.

C is the center from which lines are to radiate, making angles of 10° with each other, in this case, and starting from the horizontal line BCD. At the left the protractor (of a form with projecting legs near B and D), is placed against the T-square so that its

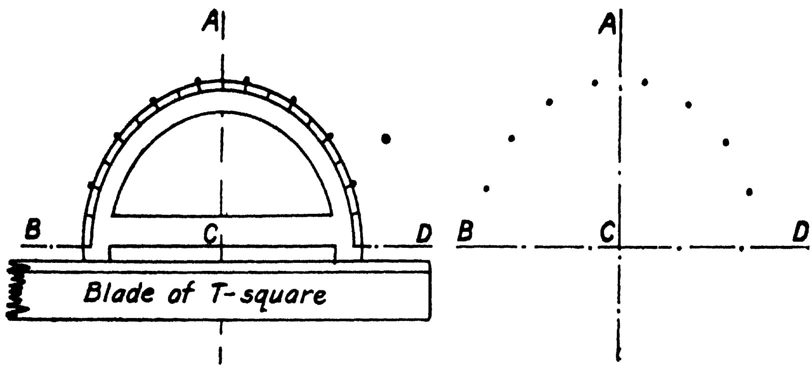


FIG. 78.

center C may be made to coincide with the point C on the drawing. Held firmly in this position points must be marked around the circumference BAD, at the required number of degrees apart, with pencil or pricker.

At the right are shown the pencil lines and dots (exaggerated) left when the instruments have been moved aside.

The dots must now be connected to the center C by lines drawn with any convenient straightedge.

By **straightedge** is meant any true edge of T-square or triangle. For large work, and for work requiring a very high degree of accuracy, draftsmen use actual straightedges of steel. These are "rulers" but not "scales" since they have no graduation marks whatever.

The triangular scale should never be used as a straightedge to guide a pencil. It is not a "ruler."

86. French Curves.—In Fig. 79 are shown four French curves, the selection from many varieties, furnished with the Naval Academy drawing outfit.

The curves act as guides to the pencil, and later to the pen, when describing curves of varying curvature. The compass, of course, is

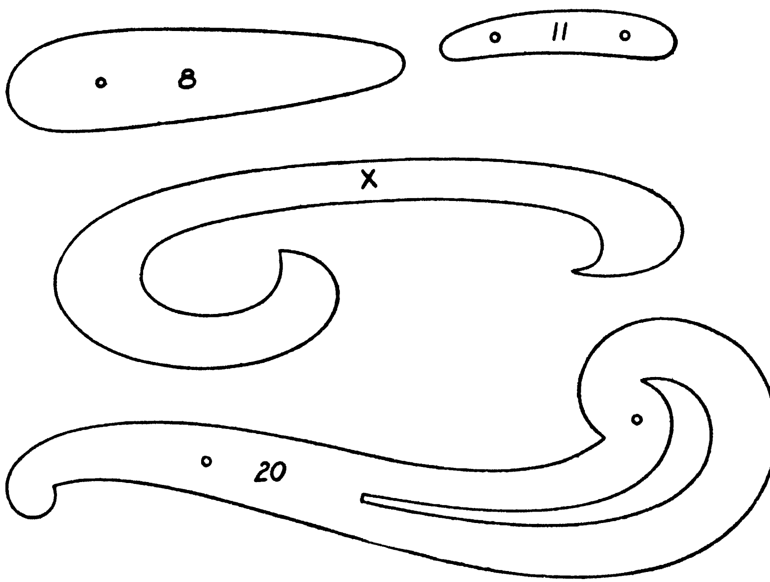


FIG. 79.

the means of describing the circle, the one and only curve of constant curvature.

The selection of parts of curves to use in specific cases must be shown later. See Art. 132, p. 103 and Art. 134, p. 105.

The curves are commonly called "irregular curves." The curves are not truly irregular but are smooth curves of very regularly changing curvature.

The Academy curves are transparent celluloid or "xylonite" and are frosted so that pencil marks may be made on them and also easily erased.

87. How to Draw Parallel Lines.—If a line is given making some arbitrary angle with the horizontal, not 30°, 45°, or any multiple of 15°, the standard method of drawing parallel lines to it is as follows: Adjust an edge of a triangle to the given line. Bring the

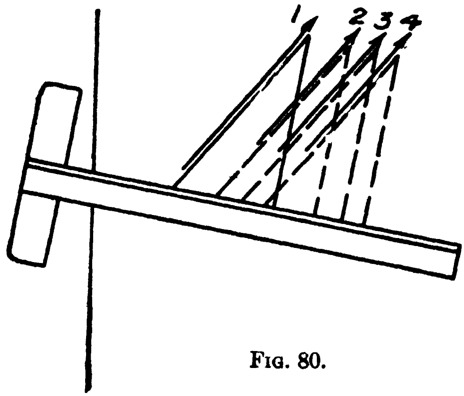


FIG. 80.

blade of the T-square against some other edge of the triangle used. By clamping the blade of the T-square to the drawing board with the left hand, leaving some fingers free to clamp the triangle when set,

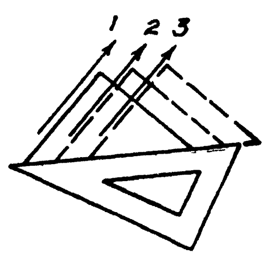


FIG. 81.

we are now able to slide the triangle to a new place, to clamp it when set, and to draw a parallel line. This process shows clearly in Fig. 80. The triangle is set to line 1, the blade set to the base of the triangle, and the triangle then moved along the blade to positions for drawing lines 2, 3, and 4.

If the lines drawn are short and close together, the hypotenuse

of the 60° triangle may be used as the straightedge, and the hypotenuse of the 45° triangle set against it, while one edge of the 45° triangle matches the given line, No. 1, Fig. 81. The object of putting the hypotenuses, or longest, edges together, is to get a firm

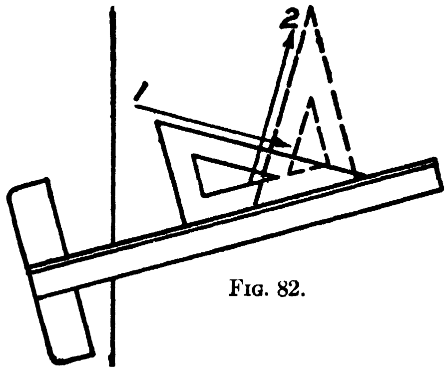


FIG. 82.

combination not easily disarranged. In these figures the lines are extended up to the right beyond the range actually available for drawing, simply to distinguish them from the lines of the triangles.

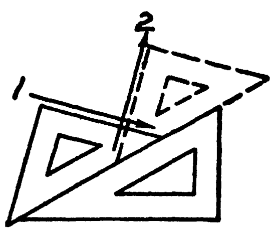


FIG. 83.

In reality the lines drawn are much closer to the drawing edges than represented.

88. How to Draw Perpendicular Lines.—The T-square may be used as a straightedge for drawing a line perpendicular to any given line at an arbitrary angle. In this case a triangle is set to the given line, No. 1, Fig. 82, and it is then reversed for drawing the

perpendicular line, or an edge at right angles with the edge set to the given line is used for the second line. This shows well in Fig. 83, adapted to drawing short perpendicular lines.

89. How to Draw Lines at 15° and 75°.—Figs. 84 and 85 show the manner of using both triangle and T-square, all at the same time, for adjusting an edge to draw a line at 15°, or one at 75°, to the horizontal. The best rule for forming these arrangements is this: Put the 60° triangle with its longest edge, the hypotenuse, against the T-square. Put the 45° triangle with its longest edge,

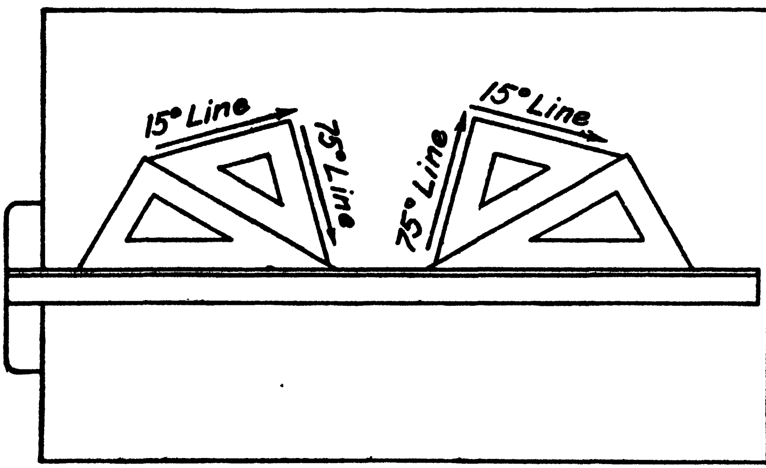


FIG. 84. FIG. 85.

the hypotenuse, **against the longest remaining edge of the 60° triangle.** This combination will be found correct for one 15° line and one 75° line. For the two remaining lines, reverse the 60° triangle and build up as before. After the triangles are roughly in place one must go through the following process to set them accurately, before a line can be safely drawn: Place T-square, holding it by its head and pressing it against the true edge of the board. Set 60° triangle against the true edge of the blade of the square, without relaxing the pressure on the head of the square which holds it to the board edge. Set 45° triangle in place without disarranging the

instruments already set. This is difficult at first, but not hard after practice.

The chief error against which the draftsman must be on his guard is shown in exaggerated form in Fig. 85-B. The 45° triangle must

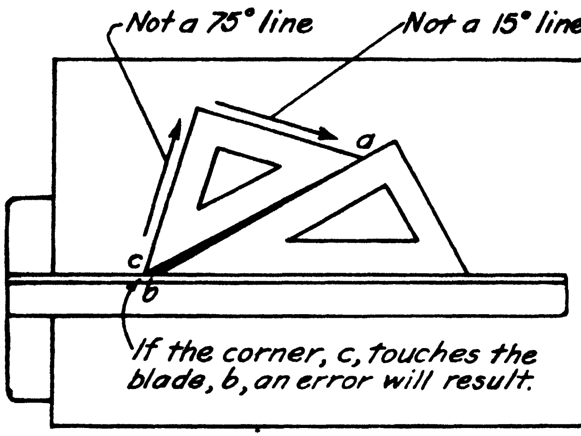


FIG. 85-B.

not be allowed to slip down until a corner touches the blade of the T-square. If it does, a small triangular space appears, shown in black in the illustration, but often quite unnoticeable in practice. This causes an error in the slope of the 15° and 75° lines equal to the sharp angle, *bac,* of the black triangle.

CHAPTER VI

FREEHAND LETTERING FOR MECHANICAL DRAWINGS

90. One-Stroke or Reinhardt Lettering.—The requirements of the present methods of duplicating drawings and of good taste combine to demand a type of lettering which shall be rapid to execute and free of unnecessary and unmeaning ornamentation. It must stand great photographic reduction in size and remain legible.

The type adopted by the Navy Department, and by the great majority of draftsmen, is that known as "one-stroke" or Reinhardt

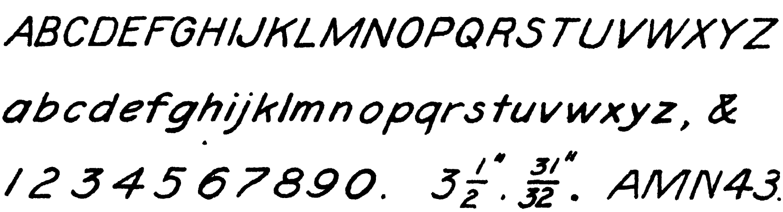


FIG. 86.

lettering. The words, "one stroke," mean one *thickness* of stroke, and imply that the width of line made by the pen in moving in any direction remains the same. This is in strong contrast to italic lettering, in which down strokes are heavily shaded, while side and up strokes are quite light. Italic lettering was once generally used, but it does not stand reduction well, and the fine lines are lost by diffusion in the process of blue-printing.

The capital, lower case letters and figures are shown in Fig. 86. Two steps are necessary in learning to execute such letters. The *forms* of the letters must be memorized, and the *means* of executing the mechanical work mastered. By tracing and copying examples of lettering, both steps should be taken at the same time. In order to memorize the forms they must be analyzed into their elements.

In this chapter the aim is to take up first the principles of design, and to follow by the methods of executing the letters.

91. Angle of Standard Lettering.—The action of the wrist in lettering has made it natural to incline letters to the right. The Navy Department has adopted an angle of inclination of 70°, others have specified 60°, or other angles, or have allowed no slope at all, keeping the lettering vertical. To understand the forms of letters it is convenient to study the upright forms and to note the effect of inclining the letters to the standard angle of 70°.

92. Simplicity of the Forms of Letters. Capital Letters.—The noteworthy feature is the extreme simplicity of the lettering and the neatness of execution demanded. There is an entire ab-

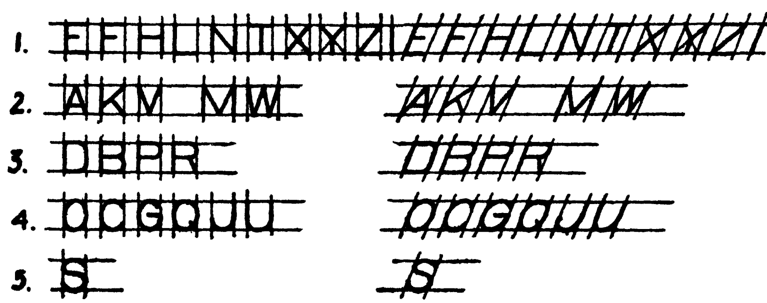


FIG. 87.

sence of the little terminal ornaments called "serifs," which appear on printed type and italic lettering.

The capitals, or upper case letters, in the upright form, are mostly inscribed in a rectangle, whose width is at least three-fourths of its height. In the inclined form the rectangle is pushed over and becomes a parallelogram whose angles are 70° and 110°.

Arranging the letters according to their degrees of simplicity we get "family groups" as shown in Fig. 87. To learn the forms study each group.

In the *first family group,* are **E, F, H, L, N, T, X, Y, Z,** and **I.**

In the *second group,* are **A, K, V, M,** and **W.** **M** and **W** are exceptional in being wider than other letters.

In the *third group,* **D, B, P,** and **R,** the letters are inscribed in the rectangle, but with some rounded corners.

In the *fourth group,* **O, C, G, Q, J,** and **U,** the letters are based on an ellipse. In the inclined form the ellipse is tangent to the sides of the parallelogram **at their middle points.** This last requirement is overlooked by many beginners.

The lone **S** on the *fifth line,* has elements of the ellipse in it. It is far the most difficult letter to form well, and requires the most practice.

93. Forms of Lower Case Letters.—Small, or lower case letters, are in general based on a rectangle or a parallelogram which is two-thirds the height of the capital letters. The bottom edges of large and small rectangles are on the same line. Many lower case letters

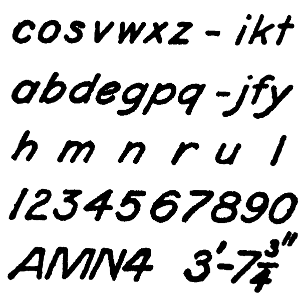


FIG. 88.

have parts which extend half the height of their rectangle above. They thus rise to the height of the capital letters. Others extend half the height of their rectangle below the base line of the lettering.

In Fig. 88 the lower case letters are grouped in family parties. Only the inclined forms are shown. In the *first line* we have seven which are exact miniatures of the corresponding capitals, namely, **c, o, s, v, w, x,** and **z. i** is a miniature with a dot over it, and **k** and **t** are miniatures modified by extending the straight stems to the full height of the capitals.

In the *second line* we have seven letters formed by the addition to the ellipse of straight stems, inclined at 70°. The ellipse has

already appeared in the first line in **o**, and incompletely in **c**. **g** has a curved stem below the line. So also do **j**, and **y**. **f** has a curved stem above the line.

In the *third line* we have five letters which consist of straight stems, long or short, connected at the tops by curves which are portions of the ellipse. These are **h, m, n, r,** and **u**. The letter **l** is a single straight stroke.

94. Forms of Figures.—The figures require close attention, especially, as they cannot be classified as easily as the letters.

They are of the height of capital letters, when used with lettering, and the fraction is twice the height of the capital. This is due to the fact that the figures of the fraction are the size of small letters, two-thirds the size of capitals, and they are separated from the horizontal dividing line by a space equal to one-third the height of the capital.

Learn the forms of letters and figures by careful study of Figs. 86, 87 and 88, and of the lower half of Plate II at p. 78.

95. Alternative Forms.—**A, M, N,** and **4** are often made with short horizontal flats at the top. This is effective in preventing blots at those points, and is particularly used when lettering is formed wider than the usual lettering. Wide lettering is very effective in titles. These alternatives are shown in the last line of Fig. 88. **3** may be made rounded at the top, and **7** may have a straight stem.

Another modification often seen in titles is the use of two sizes of capital letters instead of capitals and lower case letters. The ruling of guide lines is the same as before, the smaller capitals being two-thirds the height of the large ones.

96. Sizes of Letters.—The sizes of letters are rated by the heights of the capital letters in thirty-seconds of an inch. The smallest size used is $3/32''$ high for the capitals, and $1/16''$ high for the lower case letters. It is spoken of as size 3, and it is only used when it is necessary to get a quantity of lettering in a crowded space. The size for average use is No. 4, whose capitals are $1/8''$ high. There are also sizes 5 and 6, and even 7 and 8. The latter are used in titles only. Intermediate sizes are occasionally used.

The standard size of lettering adopted by the Navy Department is No. 4, and No. 3 is used only when lack of space for the larger

size compels it. This practice is followed at the Naval Academy, with the exception that we find it advisable to use No. 6 for practice lettering. Larger sizes are used in titles to drawing sheets.

97. Lettering Triangle.—This modification of the 45° triangle is shown in Fig. 89. It has been designed for ruling the guide lines for lettering, including 70° slope lines to establish the proper slope for inclined lettering. The small ovals with blackened center represent tapered oval holes in the triangle just large enough to let a chisel-pointed pencil pass through and touch the paper. To use the triangle as a device for ruling guide lines for lettering, place it in

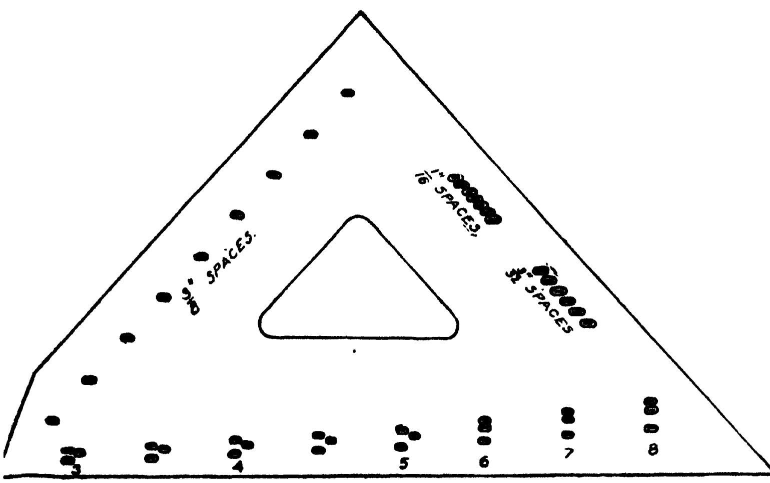


FIG. 89.

the position of Fig. 89, but against the blade of the T-square. Choose a group of three holes near the hypotenuse of the triangle and therefore near the blade of the square. Select according to the size of lettering desired. The groups are numbered in agreement with Art. 96. Place the pencil, in succession, in each of the three holes, and with a slight pressure towards the T-square, run the pencil to right or left, carrying the triangle with it. Three lines will be found on the paper, spaced to act as guide lines for the base line of the lettering and for the tops of the capitals and lower case letters.

98. Spacing of Letters.—After the forms of letters have been memorized and some practice in forming individual letters has been taken, the student begins to group letters into words. The problem of the proper space between letters and between words then arises.

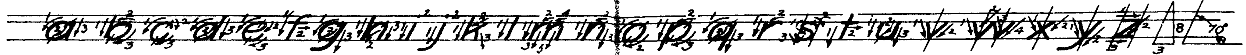
The draftsman aims to so space letters in a word that the white paper between letters may seem to be uniform in area, as far as possible though necessarily differing greatly in shape. This aim is reached partly by varying the horizontal distance between letters. A letter wide at the bottom when next to one wide at the top may move in closer to reduce the space, which might otherwise be excessive. Thus **AT** and **AV** are spaced closer together than **NK.** Another way to reduce space is to modify the forms of letters. For example **L** and **A** are both wide at bottom. If placed as near each other as they can be, without inducing a feeling that they touch, their tops, wide apart, leave a large blank area, thus, **L A.** The combination cannot be closed in like **LY.** The solution is to shorten the horizontal leg, thus, **LA.**

Spacing is thus a matter of judgment of areas and requires good attention and a good eye. A beginner, and most experienced draftsmen as well, should always letter in pencil first. After correcting for irregularity in slope and form, he should correct again for spacing in the ways hinted at above. Only a past-master can letter in ink in one step. In fact the whole process of lettering is best taken in the five steps that are given next.

99. Standard Procedure in Lettering.—The five steps in the whole process of constructing lettering are:

1. *Rule three horizontal guide lines,* spaced according to size desired. The groups of holes in the lettering triangle greatly assist in this.

2. *Rule diagonal guide lines,* at 70°, crossing the horizontal lines at about 1″ apart. The lettering triangle also assists in this, since



iiiiiii kkkkkk llllll tttttt vvvvvv wwwwwww xxxxxx zzzzz

oooooo aaaa bbbb cccc dddd eeeeee gggg pppp qqqq

ffffff jjjjjj mmmmmm nnnnnn rrrrrr ssssss uuuuuu yyyyy

a b c d e f g h i j k l m n o p q r s t u v w x y z.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z.

1 2 3 4 5 6 7 8 9 0, 3 ft-$7\frac{1}{2}$", $21\frac{7}{8}$", 4."379, 39°, 7'-$1\frac{3}{4}$".

This form of lettering has been adopted by the Navy Department. It is called "one-stroke" lettering because the width of a line does not vary with its direction.

There are three standard sizes, large, medium, and small. This is the large size, No. 6 on the lettering triangle. In it the small letters are $\frac{1}{8}$" high and the capitals $\frac{3}{16}$". Beginners should practise, chiefly, on letters of this size, and make them wide.

TWO SIZES OF CAPITAL LETTERS ARE OFTEN USED IN TITLES. THE LARGER SIZE ACT AS CAPITALS. IMPORTANT WORDS ARE CAPITALIZED. "Compressed Lettering" is used when space for wider lettering is lacking.

The medium size is No. 4 on the lettering triangle. Capitals are $\frac{1}{8}$" high. Small letters are $\frac{1}{12}$" high. It is used for all the ordinary lettering on Navy drawings.

The smallest size, No. 3, is used only in crowded places. Heights are $\frac{1}{12}$" and $\frac{1}{16}$".

101. How to Hold the Lettering Pen.—Since all are familiar with the use of the ordinary pen for "cursive," or very rapid writing, the differences in the manner of holding the lettering pen should be noted. The pen must be held more nearly perpendicular to the paper. For ordinary writing an angle of not much more than 30° is usual. For lettering, the angle should be from 45° to 60°. This is accomplished by letting the penholder lean against the first finger between the second and third joints. It does not lie deep in the cleft between thumb and first finger, and above the third joint. Fig. 90 makes the distinction clear.

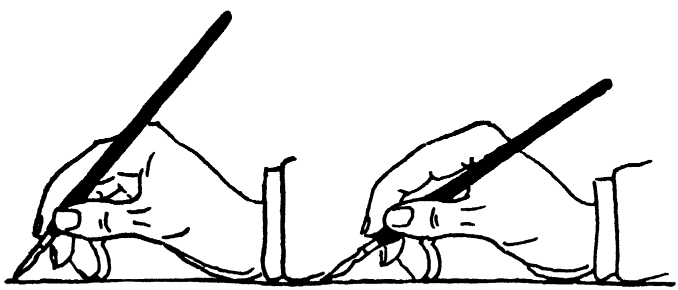


FIG. 90.

102. Division of the Letters into Strokes.—Ordinary writing has been developed for speed. Nearly all letters are run together, and without raising the pen from the paper one can trace a letter and run on to a second, third, and fourth, in one continuous curved path. In lettering, each letter is quite distinct, and each is formed by from one to five separate strokes. The name "one-stroke" lettering signifies one width of stroke only. The beginner should seek to be lavish in the number of strokes used rather than to economize on them. Any quickening of the lettering by running strokes together had better be left to the expert. In Fig. 91 the lower case letters are analyzed into strokes, which are numbered and have the direction of motion shown by the small arrows adjacent. In this figure a minute cross-line is drawn to separate the strokes whenever the point of junction is not an obvious one. The strokes

for the capital letters, where they differ from those for the lower case letters, are obvious.

103. Rules for Lettering.—A number of rules for lettering may well be collected here.

1. *Use Ball-pointed Pens for Lettering.*—These pens have a distinct portion of a sphere at the point where the pen touches the paper. The size of lettering for which a particular pen is suited depends on the size of this partial ball and not at all on the other dimensions. A large pen point may have a small ball, or vice versa.

2. *Apply Ink to the Underside of the Pen by Means of the Ink Bottle Quill.*—Don't dip the pen into the bottle.

3. *Never Vary the Pressure on the Paper.*—The aim is to get uniformity in width of line. Don't press.

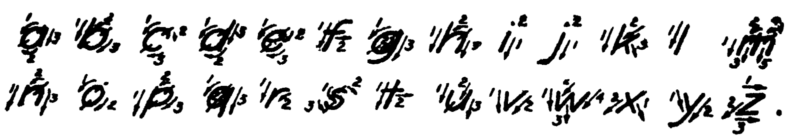


FIG. 91.

4. *At First Make All Letters Wide.*—This counteracts a natural tendency to the contrary. Writing has narrowed the letters. Consciously make them wide and you will easily fall into the practice of making the large number of separate strokes required for good lettering. Wide lettering is easier than compressed lettering.

5. *When Ink Ceases to Flow, Wipe Out the Pen with a Rag.*—Refill with fresh ink. Never put new ink on top of old. The old is already spoiled, or action would not have ceased. Do not let it contaminate the new ink.

6. *Never Erase Practice Lettering or Tinker with it.*—Use the equivalent time in practising fresh lines of lettering. It is a much better use of time, since the aim is to acquire skill, not to make a duplicate of a lettering sheet.

7. *Never Put on Too Much Ink at a Time.*—It leads to blots at the sharp angle between strokes. For example, the top of the letter A may blot if too much ink causes the ink of the second stroke to

cling to the first stroke, which is still wet. If such a blot is observed, and it is *not* due to too much ink, it is probably due to holding the pen more in the writing than in the lettering position. See Fig. 90.

104. Inking the Lettering Sheet.—Plate I should be inked or traced several times during the first periods assigned to lettering practice. These periods are only of about 30 minutes, but much practice can be obtained in that time, if none of it is wasted in mourning over blots and imperfections. These should be noted only for study, in order to detect the faults in handling which cause them. Time must not be wasted in correcting letters.

The guide lines and stroke arrows of the first line of the lettering sheet should not be copied.

Half of this practice in inking is left to the individual student, who should study his own peculiarities and his own needs. Novices, however, often show hesitation and timidity which greatly hinder the acquirement of self-confidence and skill. At the Naval Academy, therefore, we alternate the "go-as-you-please lettering" with "lettering in unison by strokes."

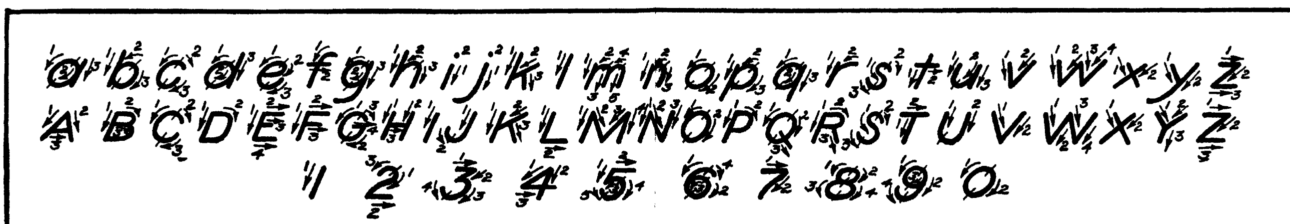
For lettering by strokes an instructor calls strokes for a whole company or battalion, much as the coxswain in a shell calls strokes for his crew. The instructor starts at a fair speed, with intervals for re-inking pens, but with no time out for corrections of any kind.

For the sequence and direction of strokes the midshipman refers to the top line of the sheet whenever he needs to do so. However, the 6th, 7th, 15th and 16th lines consist of capitals and numerals, and for the sequence of strokes for those lines the student refers to the lower half of Plate II.

105. The Lettering "Copy" Sheet.—The next step in lettering practice is to make use of a Lettering *Copy* Sheet. The upper half of the sheet in use at the Naval Academy is shown in Plate II. It is a sheet ruled with guide lines suitable for repeating the text of the Lettering Sheet. Loose copies of Plate II, printed faintly in green are issued to midshipmen in Isherwood Hall at the proper time assigned. Two steps of the procedure described on p. 74 have been performed by the printer. It remains for the student to carry out three more steps, namely:

LETTERING COPY SHEET. PLATE II.

LETTERING PRACTISE SHEET PLATE II-B.



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(3), *With sketching pencil, H or 2H, construct the letters.*

(4), *Erase badly formed or badly spaced letters and improve them.*

(5), *Ink the lettering.*

On the first "copy" sheet repeat Plate I, word for word. On a second and third "copy" sheet use other text matter, such as the *Rules for Pencil Work,* 1 to 5, printed in italics on p. 26, or the *Rules for Inking,* p. 39.

106. The Lettering "Practice" Sheet, Plate II-B.—This sheet is of the same size as the Lettering Sheet and the Copy Sheet. It has, printed in black across the top, the alphabet, both small letters and capitals, and the numerals, with their strokes. The lower half of Plate II shows this heading. Several copies, printed in black, are included in the regulation set of lettering sheets, to afford practice in the whole procedure in lettering of p. 74, Art. 99.

Thumbtack a sheet to the drawing board, making the top margin line square with the blade of the T-square. Complete the border line as indicated.

Place the lettering triangle in contact with the blade of the T-square and in the position of Fig. 89, p. 73, with the topmost beveled slit coinciding with the bottom or horizontal line of the figure 2 of the set of numerals. With the pencil in each slit, down the left side of the lettering triangle, in turn, make short horizontal pencil strokes. These will be $3/8''$ apart in vertical distance, and are intended to locate the base lines of the groups of three seen on the copy sheet. Confining attention now to the group of three slits along the bottom edge, designated by the number 6, rule groups of three horizontal lines as on the copy sheet. For each line set T-square and lettering triangle in position with the lowest slit at the short horizontal line and immediately complete that line across the page and the two companion lines also. Continue down the sheet until the field is all ruled, and the first step of Art. 99, p. 74, is finished.

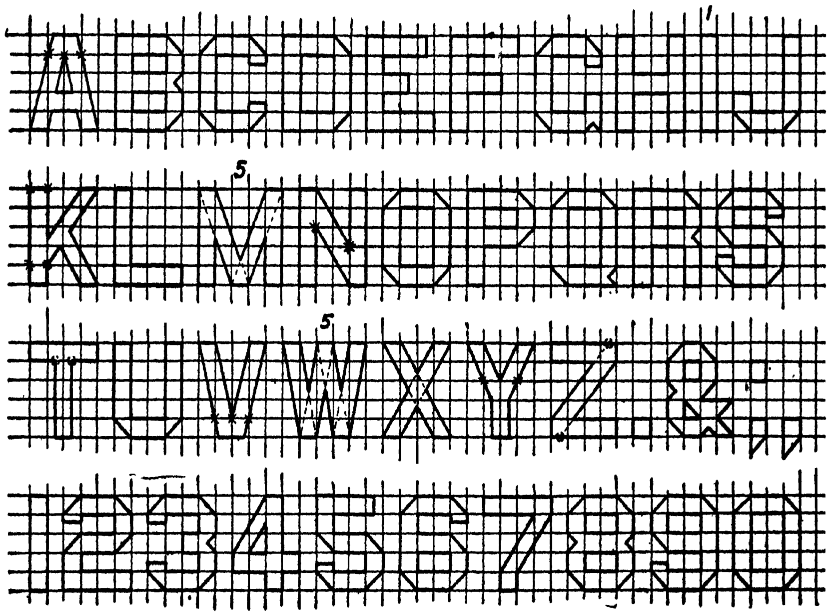
Rule the diagonal 70° lines described as step No. 2.

Finish by executing steps 3, 4, and 5 just as on the copy sheet, using any text assigned.

107. Block Letters for Titles.—Although void of true artistic merit, "block letters" are often seen on large drawings. They are particularly easy to form on paper ruled in squares.

They are not freehand letters at all, but, in deference to established custom, two alphabets are given here.

In Fig. 92 "4 × 5" letters are shown. Places marked by stars in letters A, K, N, V and Y are used to locate lines not otherwise



LETTERS, 4×5.

FIG. 92.

easy to place. The two at the top of K help locate the two sides of the low right slanting leg. The sides, continued up, would pass through the stars.

Half spaces must be estimated by eye for C, E, S, T and others. M and W are five spaces wide instead of four, and I is but one space wide.

To execute such letters on unruled paper requires that first the equivalent of rectangular ruling must be constructed.

Let us suppose that the words SHEET 1, part of the legend of the first formal drawing sheet, are to be made in 4 × 5 block letters, $^{15}/_{32}''$ high. As shown in the top part of Fig. 93, six horizontal lines are ruled by means of the group of slots marked "$^{3}/_{32}''$ spaces" on the lettering triangle as shown on page 73.

No wholesale vertical lines are ruled. As a substitute a criss-cross of 45° lines is ruled from the V.C.L. of the legend space to

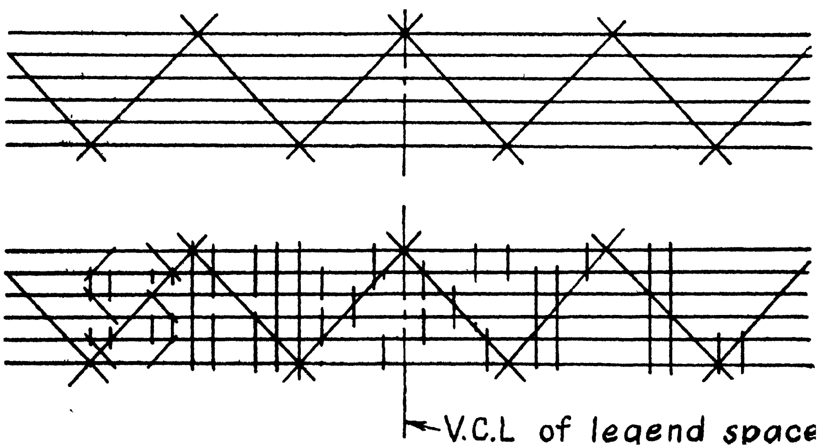


FIG. 93.

right and left. These lines, by their intersections with the horizontal lines, set the places for most of the vertical lines.

Having judged that the left edge of the second E in SHEET 1 is about the center, the V.C.L. of the legend space is used for that line, and the ruling of other vertical lines, as seen in the lower half of Fig. 93, is then performed, working right and left from the center. Some vertical lines for E and T are at half spaces. They are judged by eye. After adding six 45° lines to the letter S the work is ready for inking. After inking all excess lines are erased, of course.

In Fig. 94 a set of block letters called "one-stroke, 4 × 6" letters is shown. The one-stroke means one thickness of line as in "one-stroke freehand lettering." As shown, the thickness is that of a standard line ruled over a rectangular array of fine lines.

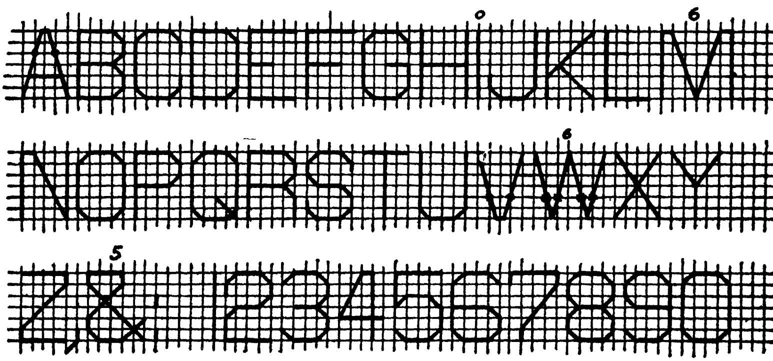


FIG. 94.

To make such letters on unruled paper, without an undue amount of work, seven horizontal lines are ruled for each line of lettering and a criss-cross of 45° lines similar to those in Fig. 93.

Block letters have little application to practical drawing, but make a useful drill for students. Large freehand capitals usually take their place in titles in industrial work.

CHAPTER VII

STANDARD PROCESSES IN DRAFTING

108. Processes Regularly Used in Drafting Practice.—Many elementary methods of handling instruments have been described in the previous chapters.

Important processes of a more advanced kind are described in this chapter which thus becomes a place of reference for steps in the manipulation of instruments. The chapters to follow will describe practice drawing sheets and will refer back to the articles in this chapter as may be needed. Each process, as used, should be memorized to make it a tool for further progress.

109. Habits of Cleanliness.—Form the habit of observing the following precautions:

1. Never begin work without first dusting the T-square, especially the underside of the blade. The T-square sliding over the paper grinds into it any dust that may have settled there.

2. After any erasure carefully wipe any rubbings from the board and the instruments. These rubbings have been electrified by the friction of rubbing and cling to the paper. Use a cloth or pocket handkerchief to brush them away. See that triangles, particularly, are free of rubbings.

3. After a severe erasure again wipe the underside of the blade of the T-square.

4. Never use a lead pencil softer than 2H on any drawing. Softer leads smudge easily and are very hard to erase cleanly.

5. Keep hands clean. Some, whose skin is naturally moist, must take particular pains not to smear their drawings. Permission to go to a washbasin to clean the hands can be obtained from an instructor when necessary.

110. Cloth Covers for Drawings.—To protect a drawing from dust and accidental injury thumbtack a cloth cover over it. If the

cloth is large fold it until a little longer than the drawing board. Tack it to the back of the left or working edge of the board. In taking it in and out of the fixed stand in which it is stored the board slides on the right edge always.

Fig. 95 shows this cloth. Before the board is put away draw the cloth over the work and tack it down, covering the working edge and the work on the face of the board, leaving the right batten uncovered where it must slide easily in the rack. When the board is taken out for work free the cloth at the right edge and throw it completely back until out of sight under the board itself when on the adjustable stand. See the position marked "cloth when folded back," in Fig. 95.

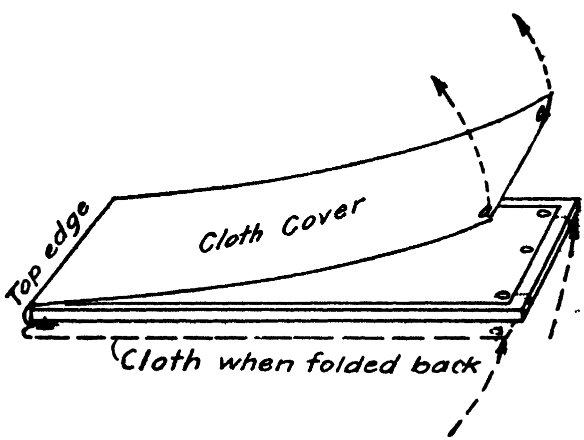


FIG. 95.

111. Distinguishing Kinds of Lines in Pencil.—While pencilling a complete observance of the Alphabet of Lines, p. 36, is not possible, since pencil lines are of one weight only. However, *center and construction lines* can be marked as such without loss of speed by the device of increasing the lengths of the dashes at will. A center line one foot long can be made by three or four long dashes and dots and yet keep its character. When inking, a uniform and reasonable length is adopted for each sheet. *Visible edges* are of course pencilled as full lines, clear and distinct.

Concealed edges, when finished *in ink,* should consist of short dashes, ⅛″ to ¼″ long, separated by spaces measuring 1/32″ to 3/32″. Concealed edges, as finished *in pencil,* can be made with dashes of double length, up to ½″. These lengths are for any drawings made in this course of instruction. Very large drawings require longer lengths to save the draftsman's time.

Fig. 96 represents the pencil work for Square 10, page 138, not knowing whether it is to be finished in pencil or in ink. Slight excess ends are usual as is explained below. If orders are given to ink such work divide each dash into two and end exactly on the side lines. For good results put your attention especially to making the spaces uniform. Erase excess ends and pencil marks in the gaps when ink is thoroughly dry. To finish in pencil erase excess ends, protecting good work with erasing shield.

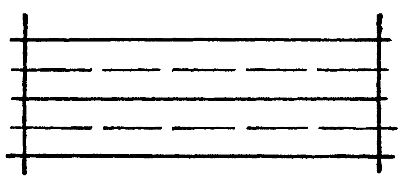


FIG. 96.

Construction lines in pencil work are of two kinds. If they are for temporary use only, they should be made faint full lines and should be erased as soon as the need for them is past.

If they record some important process which must be explained for future reference (as is often the case in the drawings made by students), then a few typical ones, the minimum needed to explain the process, should be pencilled. Use long dashes with pairs of dots so emphasized as to make an error in inking impossible. When inking the dashes, make them of the length chosen as standard for that drawing.

Shade lines are applied to ink drawings only. Make no attempt to emphasize shaded edges in pencil.

112. Pencilling Straight Lines.—It is good practice to extend pencil lines a little in excess at each end as shown in Fig. 96. Waste no time, then, in the over-careful starting and stopping of

pencil lines. Some excess is a benefit, not a harm, since it increases accuracy. Precision in ending lines is regularly left for the finishing.

Detailed instruction in handling the various instruments for guiding the pencil have been covered in previous chapters.

To guide the pencil when drawing horizontal lines follow the instructions on pages 5 and 26. For vertical lines follow pages 57 and 58. For lines at the common angles (15°, 30°, 45°, 60° and 75°), see pages 57, 60 and 66.

Lines at other angles, often called "arbitrary angles," presuppose the use of a protractor to lay off the angles (p. 62) and the use of a straight-edge to join the plotted points.

To parallel a line at an arbitrary angle, already drawn, or to draw a perpendicular to such a line follow pages 64 and 65.

113. Inking Straight Lines.—Inking is practically always done over previously drawn pencil lines. For inking, always set the drawing instruments just as they were set for drawing the pencil line, with one change only. An edge set to guide a pencil line is put about 0.″01 away from the exact line to be drawn. One can just see white between the pencil line and the guiding edge. For inking the guiding edge is moved away at least 1/32″. See Fig. 39 of page 32.

If a line has been drawn with triangle against T-square when pencilled, do not ink it using the triangle freehand and attempting to hold it parallel to the pencil line. Repeat the exact operation used in pencilling or a new and unnecessary error will be introduced.

114. Taking off Dimensions from a Scale.—The correct use of the triangular scale results in accuracy exceeding that of the eye itself. The draftsman always looks over his scale to the side away from his body and uses a pricker (a needle or a pencil as sharp as a needle), to slide down the grooved graduations of the scale to the paper. When the point touches the paper he twirls the needle to make a small prick mark, or, twirls the pencil to make a clear dot without breaking the needle-sharp point. See Fig. 61, p. 53.

115. Repeating Dimensions.—The bow spacer and the bow pencil are often used to great advantage whenever a small distance is to

be stepped off repeatedly. In Square 6 of p. 143 a distance, representing a uniform width of material between the outside edges and the inside triangular holes of a set of eight 45° triangle, appears in 24 places. The draftsman sets this distance on the bow pencil as a radius. He draws a circle at the center where the eight triangles meet, and also from each outside line, using points at random, he strikes arcs, in towards the center, as in Fig. 97.

In the complete figure there will be eight of these small arcs.

To finish the pencil work to the condition of Fig. 98, which is ready for inking, it is only necessary to draw lines tangent to the

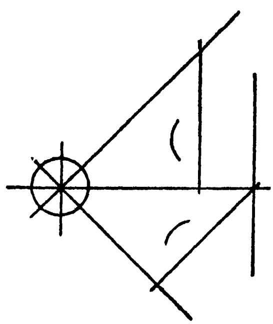


FIG. 97.

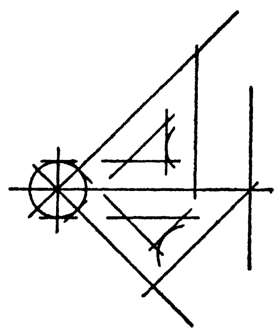


FIG. 98.

circle and to the arcs, at the required vertical, horizontal and 45° angles.

116. Subdivision of a Given Length into Equal Parts.—The need for this operation constantly arises. Several methods are in common use.

For Straight Lines.—If the line is such that, measured to any scale readily available, the required fraction is a scale distance, that scale is of course used. For example to divide $3\frac{1}{2}''$ into 7 parts, point off $\frac{1}{2}''$ spaces by scale. To divide $2''$ into 24 parts use the scale $2''=1$ foot and lay off spaces which to that scale represent $\frac{1}{2}''$.

If the distance is not recognized as a multiple of some known scale distance resort to "geometrical subdivision."

In Fig. 99 a distance AB is to be subdivided into fourteen equal parts. At an arbitrary angle a line AC is laid off starting at either end of the given distance AB. On AC fourteen equal spaces of $3/16''$, say, are laid off. Their summation should be of the same

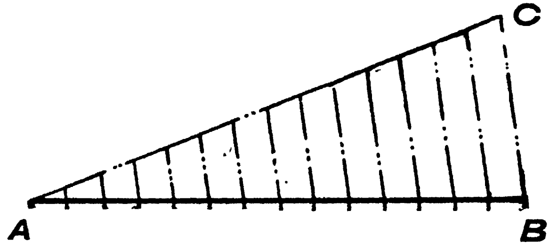


FIG. 99.

general magnitude as AB. Set the two triangles together as in Fig. 81, page 64, and set one edge to match the line CB. Draw CB and thirteen parallel lines through the points spotted on AC. These lines intersect AB at the required points of subdivision.

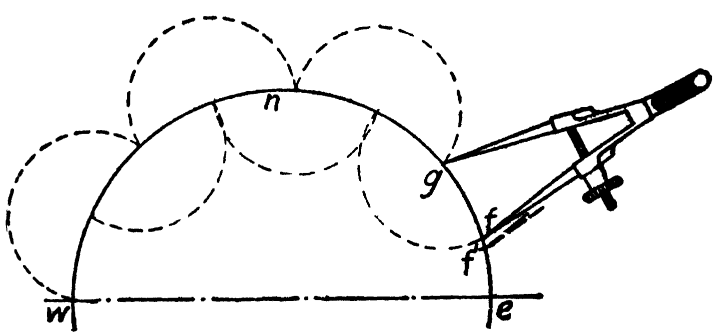


FIG. 100.

For Circular Arcs or Straight Lines.—The dividers and bow spacer are often called on for subdividing a line into a desired number of equal parts. Fig. 100 represents the first trial, and first correction, towards dividing a semicircle, *wnge,* into seven equal parts.

The bow spacer shown has been set by guess to an opening, *gf*, which the draftsman has judged to be the seventh part of the semicircle. From *w* he has stepped off this distance seven times, arriving finally at *f* instead of at *e*. *fe* is the total error. He now makes a new act of judgment and decides that *ff'* is the seventh part of *fe*. Holding the leg of the instrument at *g* he now lifts that at *f* up from the paper and unscrews the thumbnut of the bow spacer (or the hair spring adjustment of the compass), until the leg at *f* moves out to *f'*.

With *gf'* as the new setting the draftsman now steps off from *w* as before. He is certain that the error that may remain will be very much less than the first error. If not correct another trial is pretty sure to eliminate all visible error.

117. Pencilling Circles whose Centers and Diameters Are Given. —The center of a circle is very commonly given by intersecting

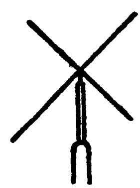


FIG. 101.

lines. To establish a mark for the needle of the bow pencil prick very slightly, as in Fig. 101, and examine the mark for accuracy. If the prick mark differs from the exact point of intersection of the two crossing lines, replace the needle and shove it in to the shoulder pressing in that direction which will carry the prick mark to the center desired. In Fig. 101, for example, let us suppose the trial prick mark to be a little south of the true point. Lean the needle well to the south and in pushing home push distinctly *to the north* as well as *in*. One quickly learns how to correct a small error accurately in this manner.

To set the bow pencil to a required diameter hold it close to the scale and set the radius by eye as well as you can. Then, on the waste margin of your sheet, draw a bit more than a semicircle and measure with the scale. In this way the error is doubled. For

example in Fig. 102 the radius was set by eye to $\frac{7}{8}''$ on the scale in use but was deficient $\frac{1}{32}''$ on that scale. This deficiency is magnified to $\frac{1}{16}''$ for the diameter. The amount to turn the screw to correct an error of a given magnitude is soon learned in practice.

118. Methods of Applying Fillets to Square Corners.—A "fillet" is the name of a circular arc, tangent to two given lines, so as to round in the corner between them.

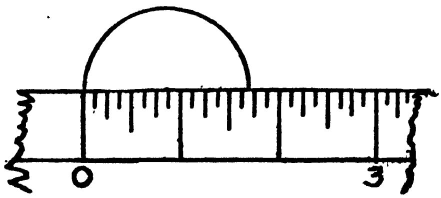


FIG. 102.

There are two recognized methods of applying a fillet to a square corner. The *full method* is as follows: Adjust the bow pencil to the radius required for the fillet. If a corner of a square is used as a center and the length of the side as radius, a quadrant of a

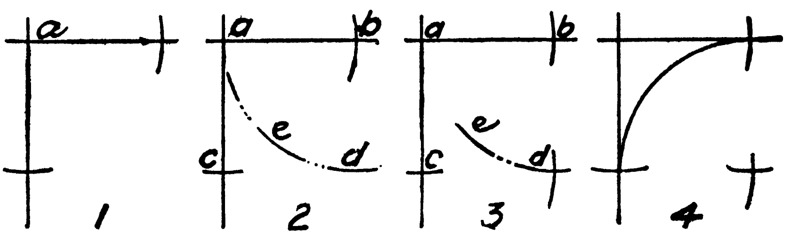


FIG. 103.

circle may be drawn, rounding off and replacing two sides of the square. The method then is to complete a square in the given right angle, using the fillet radius for the side of the square, and finally to use the corner opposite to the given right angle as the center for the fillet. The four steps are shown in Fig. 103. In the *first step*, using, *a*, the vertex of the given right angle as center, by striking arcs of the given radius, points *b* and *c* are found. These are two more corners of the square which we are constructing. In the *second step*, from the corner, *b*, an arc, *de*, is drawn. In the *third step* with *c* as center, an arc is drawn cutting *de* at *d*. *d* is the

center for the fillet. In the *fourth step* the fillet itself is drawn in from *c* to *b*. In the finishing up of the drawing the fillet is inked and the lines tangent to it at its extremities, but the sides of the square, *ca* and *ab*, are not inked.

The *abbreviated method* utilizes the fact that it is not essential to determine the points *b* and *c* with great exactness, and omits the first step. Holding the bow pencil with the lead over the point *a*, place the needle at *b* (*b*'s location can be judged with sufficient accuracy by eye) and draw the arc, *de*, as before. In the third step of Fig. 103, the point *c* is chosen by eye. Its location can be judged with sufficient accuracy from the fact that it is abreast the arc, *ed*, already drawn.

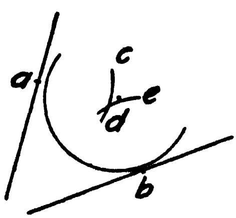


FIG. 104.

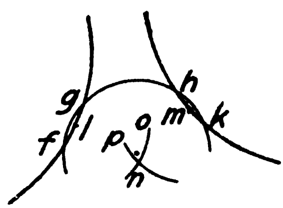


FIG. 105.

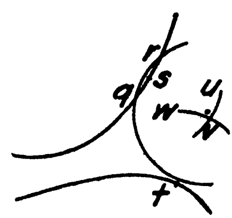


FIG. 106.

119. Trial and Error Method of Applying Fillets.—The method explained here is applicable to any angle, and in fact to circular arcs or non-circular arcs, as well as to intersecting straight lines. It is a method of almost universal applicability and is in constant use in practical work. It may be described as consisting of adjusting the bow pencil to the required radius, guessing at a center for the fillet, and then proceeding to correct the error detected until, by successive steps, it is eliminated from sight.

Figs. 104, 105 and 106 are representative figures for showing the first step in elimination in three different cases. They show only the result of the first trial and the preparations for making a second trial. The second trial can be guaranteed to be a far better one than the first. In fact it is nearly always perfect, except when the angle between the initial lines is very acute.

In Fig. 104 the given lines are straight and a first trial has been made by placing the needle of the bow pencil at the dot

shown and by drawing the large arc. It does not pay to take too much time trying to make the first trial fillet a very good one, and so it is here represented as missing the two straight lines by some little distances. Bad as it is, it gives a basis for an estimate of the points at which the arcs should be tangent to the lines. *a,* the point nearest to the trial fillet, has been selected by eye as the proper point of tangency on one line. By putting the needle of the instrument at *a,* an arc *cd* has been described. *b* has been selected as the point of tangency on the other given line, and from *b* the arc *ed* has been struck. *d* is the center for the second trial fillet, and in all likelihood the results would satisfy if the fillet should be struck from that point. The second trial fillet is not shown in Fig. 104 for fear of causing confusion.

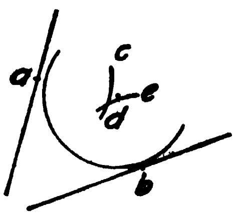


FIG. 104.

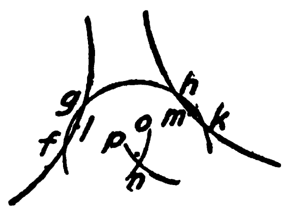


FIG. 105.

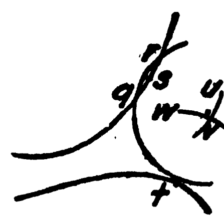


FIG. 106.

In Fig. 105, two circular arcs are the given lines which must be connected by a fillet of the given radius. In this case the first choice for center is represented by a dot, and the first trial fillet is shown cutting both given circles instead of being tangent to them. It cuts one at *f* and *g*. *l,* estimated by eye to lie midway between them, is selected as the proposed point of tangency, and the arc *on* struck from it. *m,* half way between *h* and *k,* the intersections with the other given circle, is assumed as point of tangency and the arc, *pn,* struck from it. *n,* the intersection of these arcs, is the center for the second trial fillet in this case.

In Fig. 106 two non-circular arcs are the given lines. Nevertheless the method is applicable as before. Let the given lines be straight or curved, the treatment is the same. Here the first trial fillet is represented as cutting one curve and missing the other. *s,* half-way between *q* and *r,* is taken as one point of

tangency, and t, nearest to the first trial fillet, as the second. Arcs struck from s and t give the point v as the correct center for the second trial fillet.

In all of these cases the second trial, resting on an assumption, may still be imperfect. It must be far better than the first, and if still incorrect the error left for further correction will be similar to that in Fig. 105, but of a much smaller magnitude.

This method is confessedly not theoretically exact. Methods theoretically exact, if they involve too many steps in handling instruments, are in practice more inexact than this one. It is only in theory that instruments can be handled without introducing an error at each step. A method that begins with an acknowledged

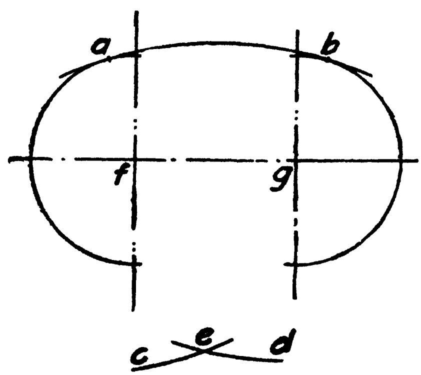


FIG. 107.

error and reduces it to an invisible one is more scientific in reality than one which builds up little unacknowledged error in a cumulative manner until a large unknown error results.

Trial and error methods for locating the centers of fillets are generally preferable to long geometrical processes.

In dimensioning a drawing the radius of a fillet is given but nothing is recorded as to the location of its center.

120. To pass a Large Circle Tangent to Two Lines.—Fillets are generally small but the trial and error methods for locating the centers of fillets are applicable to work of any size. For example, in Fig. 107 two semicircles are drawn with centers at f and g

It is required to connect them by a tangent arc of a fairly large radius. After adjusting the compass, points of tangency are guessed at, as at *a* and *b*. From them, as centers, arcs *ce* and *ed* are struck, intersecting at *e*. An arc struck with *e* as center will, in all probability, be tangent to the semicircles at *a* and *b*. If not tangent at one or both points the arc will intersect as in Fig. 105 and new arcs struck from the middle points of the intercepted arcs will give a new and improved location for *e*. The error is soon eliminated.

In Fig. 108 the same process is applied for joining two circles, centered at *f* and *g*, by a concave arc, *ab*.

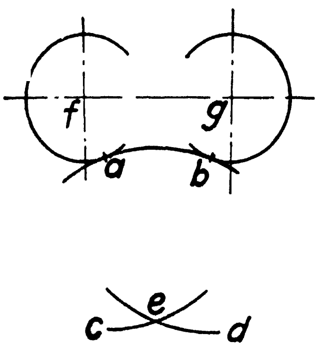


FIG. 108.

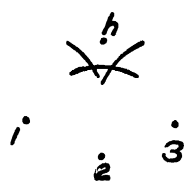


FIG. 109.

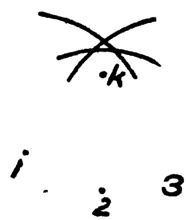


FIG. 110.

121. Trial and Error Method of Passing a Circle Through Three Points.—If three points are given, a circle may be passed through them, but the radius and the location of the center are both unknown and must be adjusted as we progress.

In Figs. 109 and 110 three given points are shown. By inspection, the draftsman makes a first guess as to the proper size for the radius, and adjusts the bow pencil to that estimate. Using the three points as centers three arcs are struck. Should they luckily have one common point of intersection that point is the center desired, and the problem is solved. In Fig. 109 is shown the result when his estimate has been decidedly under the mark. In Fig. 110 the draftsman has overestimated the radius, and again

the arcs fail to converge. In either case, however, he is in position to judge more accurately for his second trial.

A point *h*, outside all the arcs, or one *k*, inside them all, but equally distant from each, by eye, is the expected center for the second trial. The draftsman adjusts his bow pencil to the distance from any dot to *h* or *k* and strike three new arcs as before. The new radius may still be too large or too small. If so the result will be similar to Fig. 109 or to Fig. 110 but with a much smaller error. A size can soon be arrived at which shows no visible error.

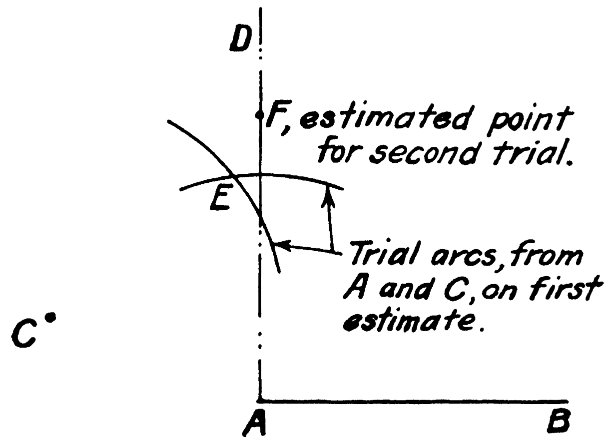


FIG. 111.

122. How to Pass a Circle Through a Given Point, Tangent to a Given Line at a Given Point.—In Fig. 111 let *AB* be a given line, and *C* a given point. A center and a radius must be found for describing a circular arc through *C*, tangent to *AB* at *A*. At *A* a line *AD* is drawn perpendicular to *AB*, by the process of Fig. 82 or Fig. 83, page 65. The center must be on this line. A first trial radius is set on the bow pencil and arcs struck from *A* and *C*. Their intersection should be on *AD* if the size selected is exactly right. If their intersection is to one side, as at *E*, then some point, *F*, on *AD*, outside both arcs (or inside both arcs), and equidistant from both arcs, is the indicated point for a second trial. New arcs struck with *CF* as radius will probably intersect as desired. If not, the error is smaller and a third trial will eliminate it.

123. Circles Have Priority in Inking.—A rule in inking which should be remembered hereafter is recorded here. **Always ink circular arcs before the straight lines tangent to them.** This rule follows from the fact that it is easier to join a straight line (or, for that matter, any curve drawn by the aid of the French curves) to the circle, than the opposite operation. To improve a junction, the right line pen may be forced in or out at the point of tangency by tilting it slightly.

124. Precautions in Inking Circles, Exact Points of Tangency.—There are three precautions which the draftsman should take when he inks his circles.

1. Due to some optical defect, **there is a natural tendency to ink too much of the arc.** This can be counteracted only by conscious

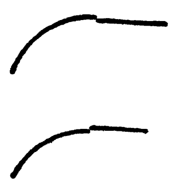


FIG. 112.

effort. Watch the radius of the compass, the imaginary line joining the needle and the drawing point. This radius is perpendicular to the direction of motion of the point. When inking an arc which joins a tangent straight line, at the exact point of tangency, the radius should seem to be perpendicular to the tangent. Start to ink the arc, watch the radius, and stop the line at the very instant the radius and the tangent seem to make an angle of 90°. The angle can be judged with little effort and with such accuracy that all danger of overrunning the arc is obviated.

2. There is a natural tendency, when drawing the tangent straight line, to make it run inside its true position for tangency rather than outside of it. In Fig. 112 the upper error is no larger than the lower one, but it is far more conspicuous, as can be seen by holding the figure at a distance. It is the one the beginner is

liable to make. Avoid this upper error by consciously attempting to produce a slight defect of the opposite kind. It is likely then to come out perfect, or the error, if there is one, will be inconspicuous.

3. When circular arcs meet at points of tangency, and the pencil work shows excess lines for each arc, as in Figs. 107 and 108, definite points of tangency may be established to make the inking easier. Thus in Fig. 113, *a* is the center for the arc *he*, and *d* the center for the arc *ef*. By joining *da* and extending it the exact point of tangency, *e*, is determined. In the same way *db* extended locates *f*, *ac* locates *h* and *cb* locates *g*.

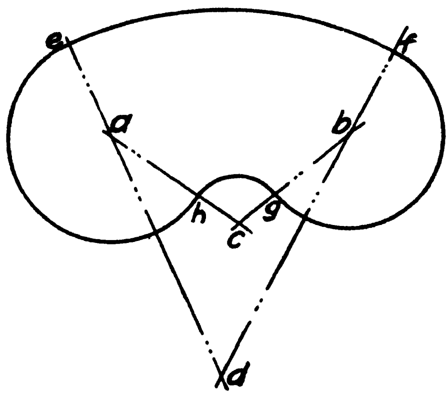


FIG. 113.

In practice one can save the time needed to draw the lines *dae*, *dbf*, etc. When inking watch the centers and start and stop the arcs when the eye tells you that the pen point, the needle and the center for the tangent arc are in line. This mental application is very rapid and as accurate as required.

125. Small Circles are Inked after Large Ones.—As a rule the smaller circles should be inked after the large ones, because a method of handling the bow pen, not possible with the compass, gives an opportunity to correct small errors, and thereby improve the work.

Ordinary circles are inked by rotating the bow pen by a twist applied to the head by the thumb and forefinger. See Fig. 115.

If an error at an end of an arc is noticed in the pencil work, then handle the bow pencil as in Fig. 114. This illustrates springing the pen point out to enlarge the radius. The pressure of the thumb and forefinger, as there placed, tends to bend the needle leg slightly.

This pressure, judiciously applied as the arc nears its end, can

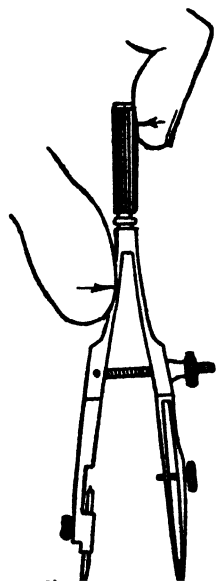


FIG. 114.

easily so increase the radius as to make a perfect fit with the work previously inked.

If the pencil work shows an error which can be concealed by decreasing the radius of the arc at its end reverse the fingering of Fig. 114 and spring the pen in instead of out.

126. Large Circles Require the Extension Bar.—Circles drawn by the compass are regularly drawn with the knees of the compass so bent as to make both needle and describing point substantially perpendicular to the paper. See Fig. 15, page 12. This limits the

use of the instrument to circles of 4″ radius or less. However, the use of the extension bar about doubles the size of circle that may be drawn.

There are two ways to handle the compass when the bar has been inserted. In Fig. 115 the thumb and forefinger twist the head,

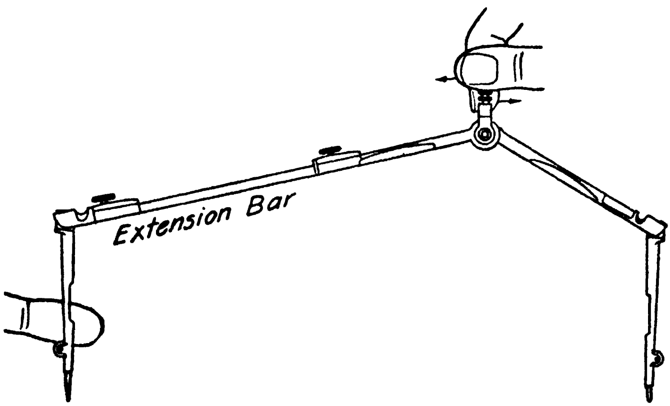


FIG. 115.

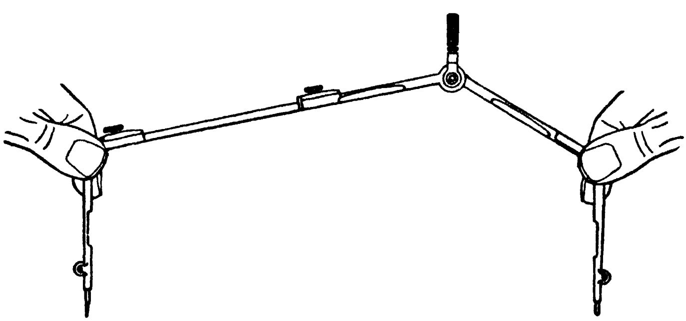


FIG. 116.

as usual, but the pencil point is checked by a finger of the left hand. This prevents sudden or uncontrolled motion, which is likely to cause faulty work.

In Fig. 116 both hands are used grasping the instrument at the knee joints. The instrument can be handled thus, very nicely,

but a delicate touch is needed. Any pressure above the necessary minimum will spring the instrument and make the radius variable.

127 "Rectification" of the Arc of a Circle.—The draftsman frequently needs to obtain the length of straight line equal to a given arc of a circle. Absolute mathematical accuracy is impossible. Accuracy such that the eye can see no error is for us sufficient. Two methods should be memorized.

In Fig. 117 an arc of a circle **not greater than 60°** is rectified thus: Draw *AH* the tangent to one end of the arc *AB* which is to be rectified. Draw the chord *BA*, bisect it at *D* and add its half length to itself, extended back through *A*. This gives the point *E*. With *E* as center and *EB* as radius, draw the arc *BF*, cutting *AH*

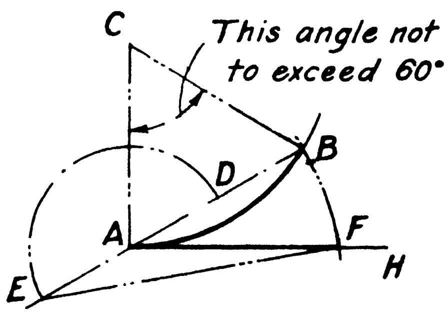


FIG. 117.

at *F*. *AF* is the length of the arc *AB*, within one-fourth of one per cent.

Arcs greater than 60° can be bisected continually until a portion less than 60° is obtained. Such a portion can then be rectified and the proper multiple of it taken to represent the original arc.

128. Rectification of a Quadrant of a Circle.—In Fig. 118 a quadrant of a circle, *AB*, with center at *C*, is shown. To rectify it draw a tangent, *AH*, at one end. From *B*, the other end of the quadrant, draw a line, *BD*, making an angle of 60° with *AH* and cutting *AH* at *D*. The straight line *AD* is equal to the quadrant *AB* within one-fourth of one per cent.

129. To Lay Off an Arc Equal to a Given Straight Line.—The draftsman often needs to convert a given straight line into an arc of a circle having a given radius. This is the reverse of the rectifying process. Let *AB* of Fig. 119 be the given straight line.

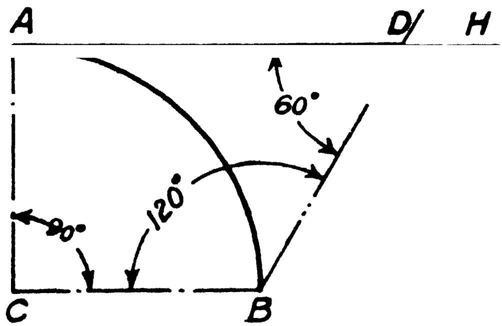


FIG. 118.

Erect *AC*, perpendicular to *AB*, and lay off on it the given radius, thus locating the center *C*. Draw the tangent arc, *AF*, indefinite in extent. Divide *AB* into four equal parts and mark *D*, so that

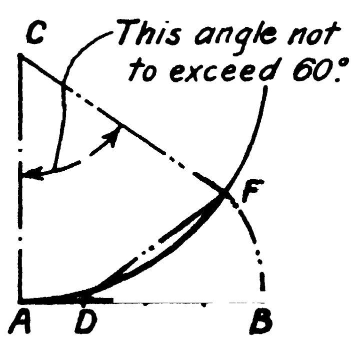


FIG. 119.

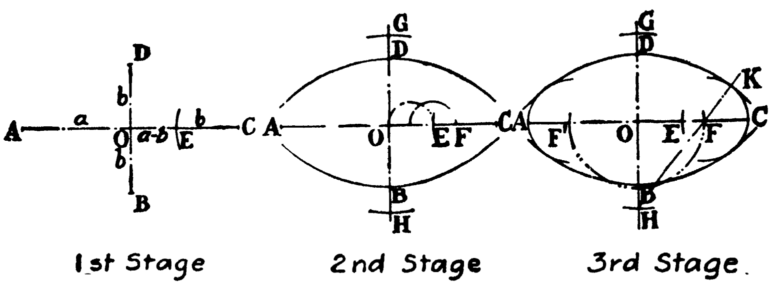
AD equals ¼ *AB*. With *D* as center and *DB* as radius, draw the arc *BF*, intersecting the arc *AF* at *F*. *AF* is the arc required, accurate to the one-fourth of one per cent, or better, ***provided that the angle ACF is not greater than 60°.***

130. The Draftsman's Ellipse.—There is a simple method of imitating an ellipse with circular arcs, known as the "draftsman's ellipse," the "two arc ellipse" or the "four center ellipse." The effect is good *if the minor axis equals or exceeds two-thirds of the major axis.* The effect is distinctly bad if the minor axis is half the major axis or less.

In Fig. 120, AC is the major axis, DB the minor axis and O the center. The distance OA is a, and OB is b. Proceed as follows:

1. From one end of the major axis, $2a$, lay off the semi-minor axis, b. This gives the point E. The distance AE, equal to $2a-b$, is the correct *radius* to use for the "side arcs."

2. Set the compass to the distance AE, and refer now to Fig.



THE "DRAFTSMAN'S ELLIPSE."

FIG. 120. FIG. 121. FIG. 122.

121. From D strike an arc, cutting the minor axis, produced if need be, at H, and, with H as center, describe the side arc through D. From B, similarly, strike an arc to determine G, the center for the side arc through B.

3. Bisect OE with dividers, and add the half of OE to itself, thus determining the point F. F is the *center* for the "end arc."

4. Set the compass to the distance FC and with F as center, as in Fig. 122, strike the arc KC. It will be exactly tangent to the two side arcs, if the work has been accurate. Determine F' by striking back from A or by making the distance OF' equal to OF.

5. For accuracy in inking, lines such as HFK may be drawn or imagined. as explained in Art. 124, Fig. 113, p. 97.

131. The Ellipse Plotted from Circles.—In Fig. 123 an ellipse is plotted from two circles, one having the major axis as its diameter, one the minor axis. In this illustration the major axis is vertical, and only the top half of the work is shown. The minor axis is horizontal. From the center, C, draw any radiating line, as $C\ 2''\ 2'$, cutting the circles at $2''\ 2'$. From these points draw vertical and horizontal lines meeting at 2. 2 is a point on the required ellipse.

In the figure radiating lines have been taken at equal intervals of 15°, thus determining five points between 0, the extremity of the major axis, and 6, the extremity of the minor axis.

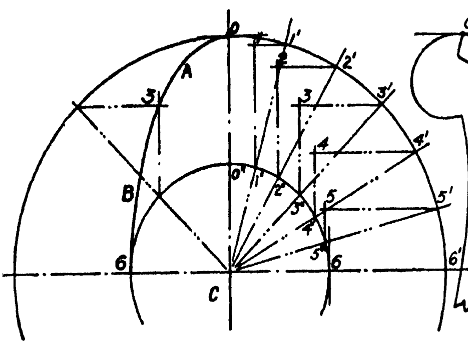


FIG. 123.

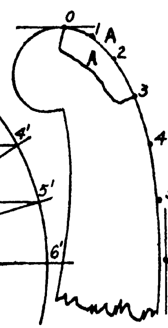


FIG. 124.

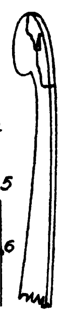


FIG. 125.

FIG. 126

Other methods of plotting exact ellipses are given on pages 170 and 171.

132. "Fairing" the Plotted Points of an Ellipse.—The non-circular curves of Fig. 79, p. 63, called "irregular" or "French," are used to follow any set of plotted points. In Fig. 124 the points 0, 1, 2, 3, 4, 5 and 6 of Fig. 123 are shown. The curve to connect them and form a quadrant of the ellipse must be vertical at 6 and horizontal at 0 so as to avoid angles at these points when the whole ellipse is drawn. We thus have nine conditions which our quadrant must obey. **It is impossible to fit a single part of our non-circular curves to the quadrant of an ellipse.** It is usually possible to fit the quadrant in two parts.

In Fig. 124 a curve has been fitted from 0 to 4, tangent as well to the horizontal at 0. **Always use a little less of a curve than**

seems to fit. In this case draw from 0 to 3. At the same time mark in pencil on the curve the part used as shown by the irregular line and the letter A. Fit another portion of a curve to the points 3, 4, 5 and 6 and to the vertical line at 6 and mark this part *B*.

To complete three other quadrants of the ellipse ignore all points except those equivalent to 0, 3 and 6. In other words, repeat the meeting point in each quadrant and fit the curves *A* and *B* in each. In Fig. 125 the curve is being turned over. In Fig. 126 it is turned over but the line *A* is still visible through the transparent xylonite. In this position *A* will fit the NW and SE quadrants.

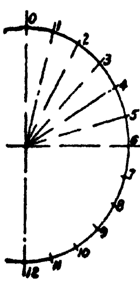


FIG. 127.

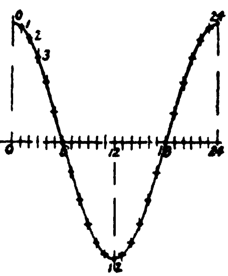


FIG. 128.

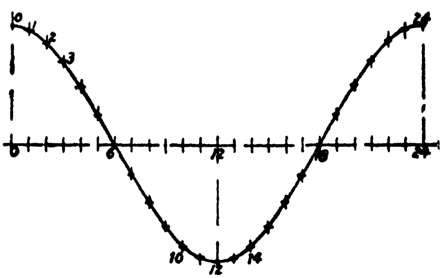


FIG. 129.

133. Plotting the Sinusoid.—The curve next in importance to the ellipse in engineering drawing is the sinusoid. It is plotted as the representation of a vibration, the simplest periodic motion, and also as the side view of the helix or screw thread.

In Fig. 127 a half circle has been divided into 12 arcs of 15°. In Fig. 128 a short sinusoid has been plotted from it by projecting, horizontally, from the points in series and by taking a short horizontal distance, $\frac{1}{20}''$, to represent the lapse of time (or axial motion as the case may be), associated with the angular change, 15°, from 0 to 1 in Fig. 127.

In Fig. 129 we have a longer sinusoid, the axial distance for 15° being twice as great as before. The axial motion for 360° is now 2″.4.

134. Passing a Smooth Curve through the Plotted Points of the Sinusoid.—If the sinusoid is a short one, as in Fig. 128, the *change*

in curvature from maximum points, 0, 12 and 24, to points of zero curvature at 6 and 18 is very rapid. Look for suitable contours on curves 8 and 11, and on the right end of curve x of p. 63. If the curve is more gradual in its changing curvature, as in Fig. 129, look to the left end of curve x and to parts of curve 20 to fit it.

Where the curve passes through points 6 and 18 of both figures it is "inflected," and, for an infinitesimal distance, it is straight. It is perfectly possible, then, to use a straight edge for adjacent parts of the curves. For both sinusoids the line joining points 5, 6 and 7 may be an exact straight line as well as not.

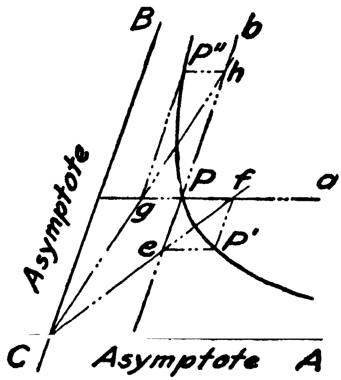


FIG. 130.

Many draftsmen prefer to use circular arcs for the maximum and minimum points of sinusoids. Figs. 109 and 110 for example may be taken as illustrating passing a circular arc through points 10, 12 and 14 of Fig. 129. If the arc is drawn, center at *h,* and it passes through points 11 and 13 as well as those given, it is obvious that we have a good imitation of that part of the sine curve.

135. The Hyperbola Drawn from its Asymptotes.—Engineers, in their study of the properties of steam and of gases and the effect of heat on them, often need to describe an hyperbola meeting the conditions of passing through some given point and approaching a pair of given lines as its asymptotes.

This problem is shown in Fig. 130, in which *CA* and *CB* are the asymptotes and *P* the given point.

Draw Pa parallel to CA and Pb parallel to CB. From C draw any radiating lines, as Cef (or Cgh), cutting the lines, Pa and Pb, in two points each, as at e and f (or g and h). These points, with P, form a triangle. By lines parallel to the asymptotes complete a parallelogram of which ef (or gh) is the diagonal. The fourth corner of the parallelogram, P' (or P''), is a point on the hyperbola.

136. Following any Set of Points with a Smooth Curve.—A series of points may be derived in some non-mathematical manner, so that they obey no known law. They may still be such, however, as to suggest passing a smooth or "fair" curve through them,

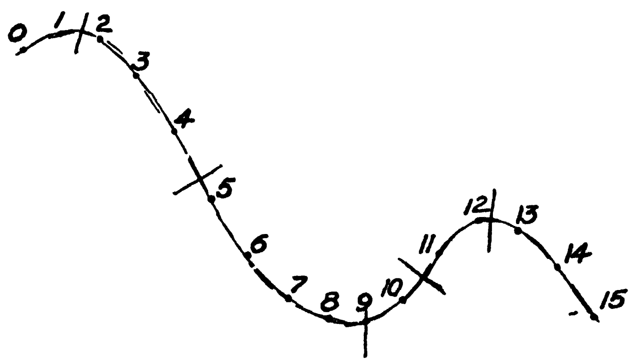


FIG. 131.

a curve pleasing to the eye and with no sudden bends or angles. This is best done in three steps.

1. *Sketch the Line.* In Fig. 131 points 0 to 15 are to be connected by a smooth curve. Use the sketching pencil and with light tentative strokes follow the points, as best you can, changing or adding strokes until the general effect is pleasing. The "fuzziness" of the resulting work is displeasing but it is only temporary.

2. *Analyze the Curve for Points of Maximum and Minimum Curvature.* Estimate the location of all points of maximum curvature (one between 1 and 2, one between 12 and 13, and one at 9), and of all points of inflection or of minimum curvature (one between 4 and 5, and one between 10 and 11). Make a short cross mark at all such points.

3. *Fit Curves to Each Part.* It will prove a simple matter now to fit curves to each part. As soon as a selection has been made erase the sketch strokes and draw the hard mechanical line. Mark the frosted curves as in Fig. 124, page 103, for the subsequent inking.

137. Standard Legend.—Every large drawing room has its own standard legend, arranged to suit the methods of filing drawings there in use, and the method of reproducing them.

In this drawing course we have adopted a simple four-line legend centered on the V.C.L. of the legend space.

The bottoms of the four lines are 3/8″ apart and the bottom of the fourth line is on the bottom working line, 1/2″ above the bottom border line. These lines may be drawn with the slots on the lettering triangle marked "3/8″ spaces."

For the first sheets block letters may be used for the first line only, preferably those of pages 80 and 81, based on squares 3/32″ in size. In that case the legend is spaced like this:

1.	SHEET 1	{Block letters, 15/32″ high or Freehand caps, No. 8, L.T.}
2.	LINE DRAWING	(Freehand caps, No. 8, L.T.)
3.	Signature 4th Class, U.S.N.A.	(No. 4, L.T.)
4.	Date here.	(No. 4, L.T.)

The "No. 8, L.T." and "No. 4, L.T." refer to the groups of three elongated holes in the lettering triangle as seen on Fig. 89, page 73. No. 8 is the one to the extreme right.

The legend space being 2½″ × 5″, its center line is 3″ from the right border line of the sheet (2½″ from the right working line). Rule this center line as a convenience in centering the legend.

CHAPTER VIII

LAYOUT FOR DRAWING SHEETS

138. Drawings Prescribed for the Naval Academy Course.—Practice is essential to the acquisition of skill and to impress the principles of drawing on the mind. Each part of this textbook is followed by a series of layouts and itemized directions for drawing sheets. Midshipmen at the Naval Academy execute a selection from these drawings, as may be directed from year to year.

The drawings which afford drill in the handling of instruments are selected from the material described in Chapter XIII, pages 137-180, a new selection being made each year according to the conditions then prevailing.

The drawings, as completed, are filed away and are returned to their owner when he graduates or leaves the Academy.

This chapter explains in detail the laying out of a sheet of ten squares, each of 3″, and each to be filled with some geometrical figure of an instructive kind.

139. Standard Size of Drawing Sheets.—The paper issued for the first sheets, and for a majority of them all, is 14″ or 15″ wide and about 22″ long. Fig. 132 shows the "layout" for a sheet 14″ × 22″. The paper has been tacked to the drawing board, up towards the NW corner, with its lower edge set parallel to the blade of the T-square in its drawing position.

The finished drawing is to be trimmed to a size of 14″ × 18″. This we will call our standard size. There is to be a "border line," in ink, 1″ within the cutting size, forming a rectangle of 12″ × 16″. The 1″ clear space outside the border line is known as the "formal margin." The cutting line is generally pencilled, but not inked, and any paper outside it constitutes the "waste margin."

Since it is to be cut away the waste margin may be used for any temporary or "scratch" purposes. In the layout shown the waste margins are two 2″ strips at the ends. If a sheet wider than 14″ is used there will be also some waste margin strips along the top and bottom.

It is not desired that any important part of a drawing should

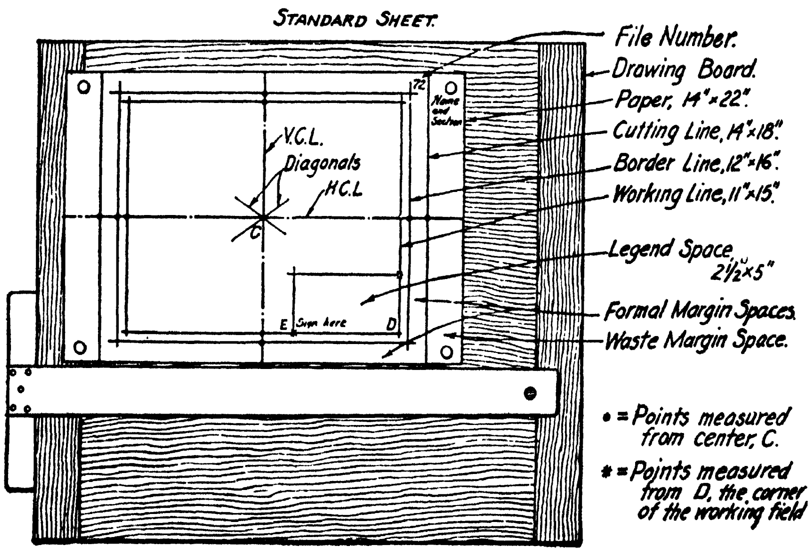


FIG. 132.

lie closer to the border line than ½″. In order to ward off such crowding a "working line," ½″ inside the border lines, is often drawn in pencil, to be ultimately erased. This rectangle will measure 11″ × 15″ and the space within it is the "working space" or "field."

In the lower right corner of the working field is the legend space, a rectangle of 2½″ × 5″.

All the lines of Fig. 132 are drawn in pencil and all except the border line are ultimately erased.

140. Layout for Sheets 1 to 4.—These sheets are for practice in making various kinds of lines. The working space is filled with 3″ squares in which the individual problems are located. The full **pencil** layout is shown on the next page, and the execution of the layout is, in fact, the first lesson in straight line drawing in pencil.

Some of these pencil lines are not to be inked at all. Others are drawn in excess of the amount to be inked.

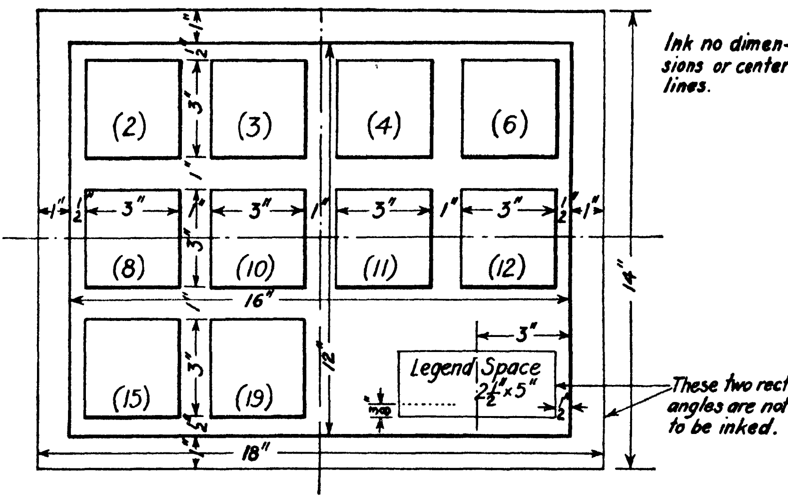


FIG. 133.

In Fig. 133 we get a clearer idea of the finished **inked** layout, with the proviso that the cutting lines, dimension lines and boundary of the legend space must not be inked.

The number in brackets within each square are a selection of ten squares, out of the first twenty, which has been used when time available has been very short and rapid progress very necessary.

A slower progression is better. For each sheet, each year, a new selection is made and announced in the drawing rooms.

141. Ten Steps in the Layout.—These are:

1. *Find the Center of the Sheet.* Use the blade of the T-square as a straightedge and draw the central portion of the diagonals of

the sheet. Prick the center, C, so found, with the needle of the bow pencil or the like.

2. *Draw the Horizontal Center Line.* Set the square almost to touch C, handling and clamping it as shown in Figs. 5 and 6 of page 6.

3. *Draw the Upper Part of the Vertical Center Line.* Follow Fig. 72 of page 60.

4. *Draw the Lower Part of the V. C. L.* Lower the T-square and set the point of the triangle to match the top part of the V. C. L.

5. *Point off the Horizontal Distances from C on the H. C. L.*

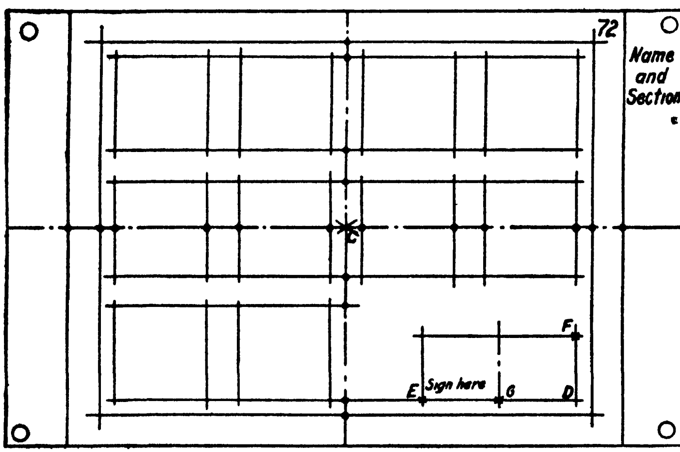


FIG. 134.

Lay the full size, 32, scale with 0 mark at C as shown in Fig. 135. Point off to the right of C distances of $\frac{1}{2}''$, $3\frac{1}{2}''$, $4\frac{1}{2}''$, $7\frac{1}{2}''$, $8''$ and $9''$. These points are shown as black dots in Fig. 135, and also in Fig. 134. Use a pricker, or a H or 2H lead, as depicted in Fig. 61, page 53. Twirl the pencil to make the mark so as not to break the lead.

Point off the same series of distances to the left of C.

6. *Point off the Vertical Distances from C on the V. C. L.* Lay the scale so that the 0 mark matches C and point off on the upper half of the V. C. L. the series of distances; $1\frac{1}{2}''$, $2\frac{1}{2}''$, $5\frac{1}{2}''$, $6''$ and

7″. If the sheet is only 14″ wide the 7″ mark will be on the edge itself.

Point off the same distances from C, down, along the lower half of the V. C. L.

7. *Square Out the Horizontal Lines.* Through all the dots on the V. C. L. shown in Fig. 133 draw long horizontal lines nearly across the paper.

8. *Square out the Vertical Lines.* Set the T-square and 30° triangle, as before, and draw the tops of all the vertical lines. As shown in Fig. 133 these are not continuous lines but extend about ¼″ beyond the horizontal lines the ink lines must end on. Set to all the dots on the H. C. L. from left to right.

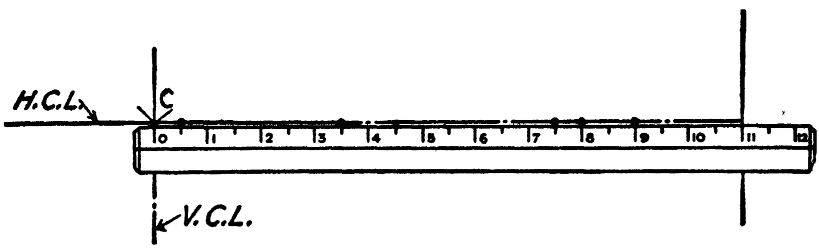


FIG. 135.

Move the T-square and triangle down and draw the lower portions of the lines, joining them accurately to the upper parts.

Lay off a 5″ distance from D to E and draw the vertical through E, to limit the legend space. Draw also the V.C.L. of the legend space for centering the wording, if block letters are to be used for the first line.

9. *Erase Excess Pencil Lines.* Rub out excess lines until the design shown in Fig. 134 becomes evident. Leave some slight excess at each corner.

10. *Check and Correct the Squares.* Slight errors between the squares are harmless. Errors in the widths and heights of squares cannot be tolerated. Measure each distance by scale and if any error is detected erase a side of a square and replace it at 3″ from the remaining side, after a new measurement has been made. Check the dimension again. Each square must measure 3″ as perfectly as the eye can judge.

This layout is the first serious pencil drawing you have to make. Learn from it to **work from center lines whenever a drawing is symmetrical**, or any considerable part of it is symmetrical. The H. C. L. and V. C. L. play a large rôle in engineering drafting.

142. Signing and Identifying All Drawings.—Each midshipman is given a "file number." This number is permanent for him and should be recorded on the first fly leaf of the text-book.

As part of the laying out of any sheet, as soon as the border lines and cutting lines have been established. put your file number, in pencil figures ½″ high, *in the upper right corner of the formal margin.* This is just where an assumed file number of 72 has been placed in Figs. 132 and 134.

As soon as the legend space has been located, *sign your name in pencil in the proper place.* It is where "Sign here" is shown in Fig. 132, page 110, ⅜″ above the working line (or ⅞″ above the border line) towards the left. Later, if the sheet is inked, erase the pencil signature and sign with ink.

Where "Name and Section" are shown in those figures, *in the upper right corner of the waste margin,* record these items as a convenience to your instructor.

These rules facilitate keeping track of sheets even if they are unfinished or accidentally get adrift.

CHAPTER IX

PENCILLING THE FIRST DRAWING SHEETS

143. Squares for Sheet 1.—A selection of ten squares from those in Chapter XIII will constitute the first drawing sheet. The particular squares selected will vary from year to year according to the time available. There is material for four sheets of ten squares in all, but, as a rule, thirty squares should suffice. The additional ten may be used to occupy the time of exceptionally fast students.

For the first sheet or two the pencilling of a horizontal line of four squares may well be assigned and this task followed immediately by the inking of the same four squares. Another four squares may then be pencilled and inked, and so on.

Whenever pencilling is assigned read this chapter, or at least refer to it, to refresh the memory of the steps here described, until they are known by heart.

Whenever inking is assigned read Chapter X in the same way until its contents also are known by heart.

144. Directions for Pencilling Each Square.—The squares of Chapter XIII are illustrated as fully inked (some also as shaded) but the detailed directions under each figure are for the pencilling only. When reference is made to the use of a particular instrument the student, if uncertain of its meaning, should reread that one of the first seven chapters, pages 1 to 107, giving information on that particular subject. If not found at once under the appropriate chapter heading, such as "Pencil Instruments," "Flat Instruments," "Freehand Lettering," consult the general index, pages 563 ff. Learn to use this index and the indices of your other textbooks when you come to them.

A résumé of some important points in pencilling which must be kept in mind constantly is given in the next few articles.

145. Pencil Leads and Their Sharpening.

1. *For Drawing on Unruled Paper.*—4H lead, sharpened to a narrowed chisel, duckbill chisel, or elliptical chisel. Resharpen whenever a flattening across the end can be seen in the case of the duckbill or elliptical sharpenings, and whenever a bright shine can be seen on looking straight at the end of a flattened chisel. **In the author's opinion the duckbill or rounded chisel is the best for general use.**

2. *For Drawing Over Ruled Lines.*—2H lead. Follow the same sharpenings and rules for resharpening. Somewhat blacker lines are needed to predominate over the ruled lines. This is the reason for the somewhat softer lead.

3. *For Sketching.*—2H lead. A cone point, slightly rounded, is used. It should not be as blunt as the point ordinarily seen on the pocket lead pencil.

4. *For Pointing Off Dimensions.*—2H or 4H lead, sharpened to a long cone. Expose about 3/8″ of lead and sharpen to a needle-like point. A pricker, or any form of metal needle convenient to handle, may be used as a substitute, but the prick marks made must be fine to prevent permanent injury to the drawing. Dimensions can be taken from the scale with the cone or needle sliding in the grooves of the scale.

5. *For Large Compass.*—4H lead. Any form of chisel sharpening may be used, provided the edge of the chisel is exactly in line with the direction of motion of the pencil point. It must appear to the eye to be at right angles to the line joining the pencil point to the needle point of the compass. 1/4″ of lead, or more, must be exposed, and the needle set out to suit. The extreme point of the needle should extend beyond the lead, but the shoulder of the needle should not.

6. *For Bow Pencil.*—4H lead. In the usual form of instrument the lead holder is set at an angle pointing in toward the center. In that case the only proper sharpening is the elliptical chisel sharpening, produced by exposing about 3/8″ of lead and cutting a long slant on the inside, as in Fig. 29, page 22.

As shown in that figure, the needle should have a flat side, and in addition to adjusting it to exceed the lead in length, at the point but not the shoulder, the flat side should be turned to face the lead.

146. Characteristics of Pencil Lines.—Pencil lines are drawn with the pencil held almost exactly vertical, moving in a direction, as much as possible, away from the body. The lines drawn are distant about $1/100''$ from the guiding edges.

In general, pencil lines follow the "Alphabet of Lines" used for ink work, except that no distinction in width is attempted, and therefore no shading in pencil.

There is one other exception. In ink, lines for concealed edges are made of very short dashes and short and even gaps. Though spaced by eye, great care is needed to produce good results. In pencil, to save time, particularly when the work is tentative or subject to change, lengthen the dashes to $1/2''$, twice the limit in size for ink lines.

If a concealed edge is to be finished in pencil, and its exact location and points of ending are known from the start, draw it at once as it is finally to be. Keep the *gaps* in the lines uniform.

Pencil lines to be inked are expected to exceed at their ends their true limits by a slight amount. This overrunning saves time. Also other lines may need to end at the same point and the eye judges more accurately the exact intersection of two crossing lines than the point of meeting of two lines at a corner.

147. Order of Executing Pencil Work.—When possible to do so, draftsmen follow, step by step, an order of pencilling which greatly quickens their work. For a compact description which will serve as a review of previous work, and be available for future reference, we give on the next page a series of six steps to illustrate the standard progression. The piece chosen is a toothed rack with flanges and bolt holes for securing it to some firm foundation, and it has been selected because it combines horizontal, vertical and slant lines, and circles, arcs and fillets. The final result, shown in square 6, is three views of one object related to each other in a way to be made clear in Part II of this book.

In advance of practical experience in pencilling, the student will be unable to appreciate the full significance of these steps. One reading of this chapter will not be adequate by itself. Turn back to it hereafter as you will need to and your speed will be much improved as its full meaning sinks in.


1.
Center Lines.
2
Chief Circles.
3
Squaring Out.
4.
Fillets. Slant Lines.
5

Fig. 136.

The first thing to notice is that **all views are drawn simultaneously, no one being given precedence over the others.**

The six steps in pencilling are as follows:

1. *Center Lines.*—All symmetrical parts are marked by center lines. These are the first lines laid off. For views which are not symmetrical, some large plane face is selected as a base line. In this case the actual base serves this purpose. Among the center lines are included those for the chief circles which appear on the drawing. On the center and base lines some prominent dimensions are pointed off in preparation for the next steps.

2. *Chief Circles.*—These are drawn next, in whatever views they may appear. The great advantage in this step is the economy in measurements effected. A chief circle, once correctly described by the compass or bow pencil, often projects to two other views without further measurement.

3. *Squaring Out.*—This operation is the drawing of the principal horizontal and vertical lines, some through the points of measurement on the center lines and base lines, in 1, and some by projection from the chief circles in 2. The geometrical construction has been used to mark off the teeth of the rack. Each tooth is $\frac{2}{3}''$ in width, and this size does not appear on our scale. The bow spacer might be used instead.

4. *Fillets. Slant Lines.*—Fillets are the minor circular arcs, chiefly for rounding off corners. No record of the center of a fillet is kept, only the size of the radius is of importance. The slant lines are applied at this time, thus substantially finishing the drawing.

5. *Dimensions.*—The drawing may be cleaned up, especially construction lines, like those used for the teeth, and wherever lines are greatly in excess. They are not erased to the corners, however, since a slight excess is an aid to the inking. The dimensions are now applied, lines, arrowheads and figures. Features which are duplicated are dimensioned in one place only.

6. *Hatching. Lettering.*—The hatching is started to indicate slope of line chosen, width of spacing, and character. The latter depends on the material. In this case brass is indicated. Hatching should not be finished in pencil when the drawing is to be inked. Any notes to assist the mechanic in manufacturing the article are

added in the form of "labels," in the clear places, with lines leading to the particular features referred to. For example, the words "½″ drill" direct the mechanic to drill the holes shown with a drill of that size, and the words "½″ tap" direct him to drill that hole to a smaller size (obtained from a table of tap sizes), and then to thread the hole by screwing through it a "tap." This is a threaded rod of ½″ size, made of tool steel and converted into an instrument for cutting a standard ½″ thread on the inside of the drilled hole.

148. Specific Directions for Pencilling Sheet 1.—Each square has its own detail directions for pencilling under its illustrative figure, but the figure is the square as inked and the pencil work will differ from it much as the figure on page 112 d'ffers from that on page 111.

Beginners in drawing may well adopt the following policy:

(1) Consider all the first lines as tentative. Draw them with 4H pencil and not too much pressure. Allow plenty of overlap.

(2) As the work progresses and the positions, ends and characters of lines become certain, erase incorrect lines, all but a minimum of excess ends, and all construction lines except those purposely retained to show method used. Go over faint lines with greater pressure.

(3) If orders are given to *finish the drawing in pencil* there will be little more to do in cleaning up and correcting. A few corners will need to be emphasized with 2H pencil.

(4) If orders are given to *finish in ink* follow the instructions in the next chapter.

CHAPTER X

INKING THE FIRST DRAWING SHEETS

149. Inking Mechanical Drawings.—The novice is immediately impressed with the difficulty of inking a drawing without thereby completely spoiling it.

However, when a definite system and plan is understood and followed, much of the confusion, delay and risk of accident disappears.

No specific directions for inking each square of Chapter XIII are given. The student must apply general principles as given in Chapter III, Ink Instruments, pages 27-44, and as summarized in this chapter.

150. Pens and Their Adjustment and Care.—Ink work is executed over pencil work, except hatching lines. The character of lines used are those known as the "Alphabet of Lines" shown on page 36. They will be seen illustrated, in part, in Fig. 137, page 123.

In order to pass rapidly from one size of line to another, the adjusting screwhead of the pen should have an index mark scratched on it, as shown in Fig. 43, page 34. This mark is put on after a careful adjustment of the pen as described in the pages immediately preceding that referred to.

The following rules should be observed:

1. *Apply Ink Only with Quill of Bottle and Never Fill More than 1/4″ of the Length of the Pen Blades.*
2. *Wipe All Traces of Ink from the Outside of the Blades.*
3. *Never Lay Down a Pen Full of Ink: Wipe it Out.*
4. *Never Put New Ink on Top of Old: Wipe Out the Old First.*
5. *Clean Pen Thoroughly, with Water and Rag, Once a Day.*
6. *Hold Pen Vertically.*—This makes the ink line stand away from the guiding edge about 1/32″.
7. *In Inking Repeat the Manipulation of Instruments, Step for Step, as in Pencilling.*—No tendency to depart from the pencil lines will then arise from handling the instruments in a new manner.

Thus, if a line is drawn in pencil with triangle against T-square, do not draw it, while inking, with triangle alone.

8. *Never Erase a Wet Ink Line.*—Let it dry out completely, and then erase with rubber erasers, **not with steel knife.** The knife is used for trimming. (See page 43.)

151. Order of Executing Ink Work.—Six steps are also shown for this in Fig. 137. They are not equivalent to the steps in pencil work, but differ for the first four steps. This difference arises from the fact that ink work is executed over the pencil work, in all but the hatching. In Fig. 137 it has been necessary to omit the pencil work, but one must imagine all this work to be executed over No. 6 of Fig. 136. The steps are as follows:

1. *All Circles.*—The chief circles and the fillets are inked wherever they appear. Care is taken not to exceed by the smallest amount the length of arc needed. There is a natural temptation to excess due to some optical defect. One must guard against it at all times.

2. *Horizontal Lines.*—Ink these as they come, from top to bottom, changing the setting of the pen for each character of line.

3. *Vertical Lines.*—Ink these from left to right, as they come.

4. *Slant Lines.*—Ink these as systematically as possible. In this example there are two pairs of 45° lines in the plan, the upper left drawing, and one set of slant lines for the teeth in the front elevation, the drawing below it.

5. *Dimensions.*—This step follows that in the pencil work exactly.

6. *Hatching. Lettering.*—The hatching differs only in that it is completed in ink. In pencil it is only started or "indicated." The lettering is executed over the pencil lettering and should be an improvement on it. One unconsciously improves lettering when it is over pencil work. For this reason only an expert should attempt to letter directly in ink, without previous pencil work as a guide.

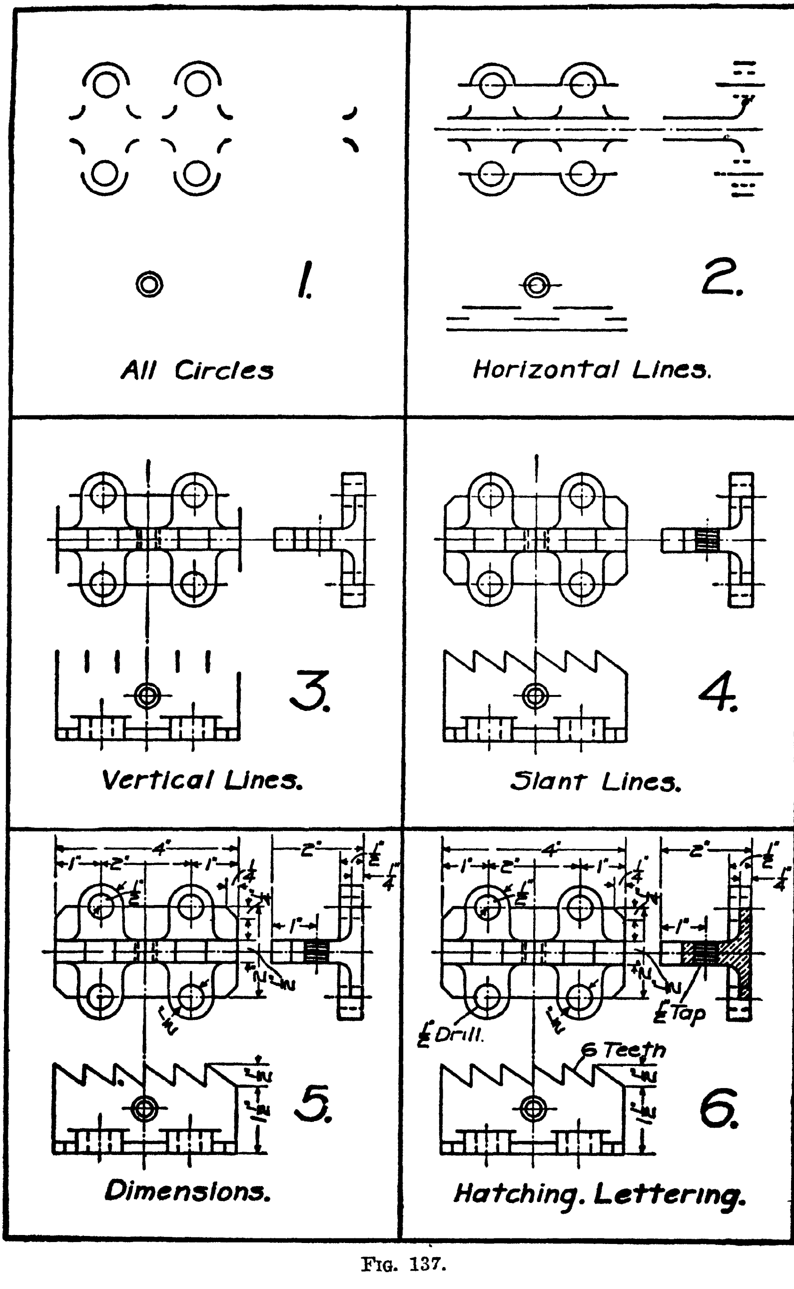

1.
All Circles
2.
Horizontal Lines.
3.
Vertical Lines.
4.
Slant Lines.
5.
Dimensions.
6.
Hatching. Lettering.
Drill.
Tap
6 Teeth

Fig. 137.

152. Specific Directions for Inking Sheet 1.—Little can be given except that the steps in inking should be applied as systematically as possible.

Sheet 1 is presumably concerned with figures composed of straight lines. It is often wholly of straight lines and given a title, on the second line of the legend, of STRAIGHT LINE DRAWING. For the first four squares at least there are no circles and therefore no Step 1 in inking. The other steps should be followed carefully. In Step 2 put the T-square on the board and ink first the top border line. Then move down to the top line of the four squares. Then slowly move down, inking each horizontal line as it appears above the T-square blade. If a center line or shade line is encountered change the setting of the pen as described on page 35, Art. 54. Pause after the horizontal lines for the ink to dry.

In Step 3 move from left to right with triangle on T-square like Fig. 69, page 58.

In Step 4 the slant lines must be divided into sets or groups and a pause for ink to dry is necessary between inking each set.

On every occasion when inking is required try to apply the steps logically, carefully and without undue haste. Speed comes from following the system.

If one or more of squares 35, 36, 37 and 38 (pages 176-179) are assigned, the directions for inking the "graded lines" suggesting curvature will be found under each particular square printed in italic lettering. This is a special kind of inking, not standard inking at all.

CHAPTER XI

SHADING IN MECHANICAL DRAWING

153. Shading and Shade Lines.—Shading is of little value on drawings of simple things. For drawings of complicated things it becomes valuable and for textbook illustrations of machinery it is almost invaluable. Sooner or later shading must be understood.

Many squares in Chapter XIII have shaded figures. Shading such figures is merely copying, and requires no thought.

Shading was long ago an intricate study of shadows and had to follow the course in orthographic projection (Part II). It has been so simplified that now the chief difficulty is in handling the instruments, and it may well be treated here.

When not a matter of copying only, the student must consider each line and shade those for which he can give an adequate reason, based on the following articles.

154. Theory of Shading.—A shade line is in theory a shadow cast by a raised object. It must depend, then, on the direction of the lighting. Regarding the object drawn as lying flat on the drawing paper, we imagine the light which strikes it to come **from almost directly above the object.** The light does not fall on the paper at exactly 90°, but at a slightly reduced angle, one diminished from 90° by what the mathematicians call an "infinitesimal" angle. This slight inclination of the ray of light is such that we may say that it comes **from the NW.** These two ideas are not inconsistent with each other. The light is almost àt 90°, but its departure from the perpendicular is such that its "projected direction" is a 45° line, a line such as NW-SE.

155. Application to Determining Shadows.—A shadow marks a separation of an illuminated surface from one not illuminated.

From the rule of lighting given above we note that any surface visible as an *area* (not seen on edge as a line only) is illuminated. Only surfaces seen on edge or surfaces underneath other solids can be dark surfaces.

156. Shading of Vertical Surfaces.—Surfaces perpendicular to the paper are illuminated or dark according to position. In Fig. 138 various positions of triangles are shown together with arrows giving the projected direction of light. What we call the edges of the triangles are surfaces perpendicular to the paper though only about $1/16''$ thick.

Look at each edge in turn and note why it is shaded or why not shaded. Surfaces facing S or E or SE are shaded. Those facing N, W or NW are not. One facing exactly NE like *u* has a skimming light and is not shaded. *q*, facing SW, is not shaded.

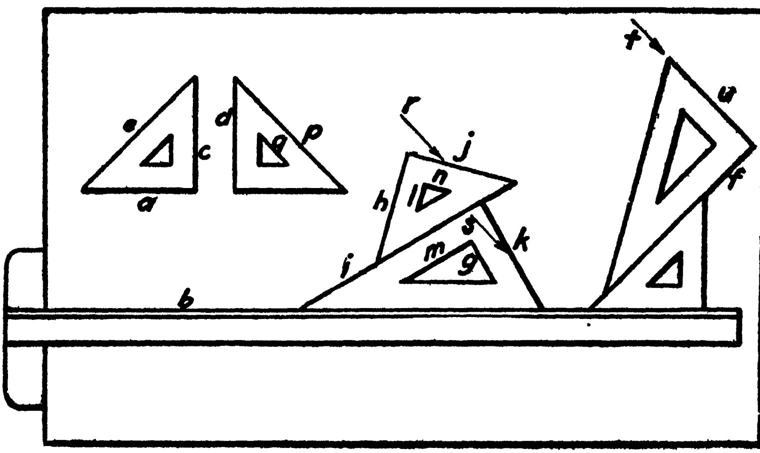


FIG. 138.

When two triangles of equal thickness are pushed together, making one flush surface with a mere line of separation but no finite distance between them, there is no shadow created and no shade line required.

In Fig. 139 the shading on the S edge of *a* shows that *a* is higher than *b*. The lack of a shade line where *d* is in contact with the edge of *c* shows that *d* is as high as *c* or higher than *c*. It is to give information of this kind that shading is used.

In Fig. 138 the triangles touching the T-square are not shaded on their S edges. The edge of the blade of the T-square at *b* is therefore equal to or thicker than the triangles themselves.

157. Shading of Rounded and Undercut Edges.—If rounded edges have any part actually perpendicular to the paper and are in the same positions in relation to the light as the square edges already considered, they are shaded or not shaded exactly as before.

Thus a cylinder whose axis is parallel to the paper always has one edge shaded, unless its axis lies exactly NW-SE. Undercut edges, whether sharp or rounded, follow the general rule.

An exact half cylinder, which the mechanic calls a **half-round**, lying with its flat side on the paper, is shaded just as the full cylinder is. This is not an undercut edge and the surface perpendicular to the paper is infinitely small, but it is shaded. A lengthwise slice of a cylinder, less than a half cylinder would not be shaded.

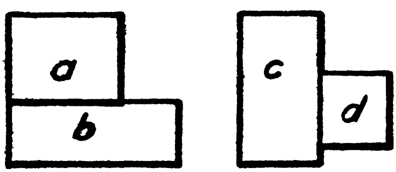


FIG. 139.

A shade line is virtually a statement that the surface is at that point perpendicular to the paper and that it faces to the E, SE or S.

158. Test for Position of a Perpendicular Surface.—In the act of shading a drawing, a test is frequently needed to determine whether a perpendicular surface receives light or not. Since the NW-SE line is the dividing line, the 45° triangle in the second position of Fig. 138, that with edge marked *p*, is used as a criterion. Consider this edge as the projected ray of light. If it falls *on* or against a perpendicular surface it is illuminated. If it falls *over* the edge is dark. See arrows *r*, *s* and *t*. The surface *u*, receiving a skimming light, is considered illuminated and is not shaded.

159. Curved Surfaces Perpendicular to the Paper.—We have considered straight edges so far. If a disc, such as a button or a washer, lies on the paper it will have perpendicular or undercut edges which at some places are illuminated and at others are dark.

How do we determine what parts should be shaded and how taper off from shade line to the standard unshaded line?

Two ways of testing the end of a cylinder or disc are shown in Figs. 140 and 141. If the cylinder is known to be a circular cylinder then the 45° triangle, placed so as to cut the center of the circle, slanting SW-NE as in Fig. 140, marks the points *a* and *b*. We know that the semicircle *bca* is illuminated and the semicircle *adb* is dark.

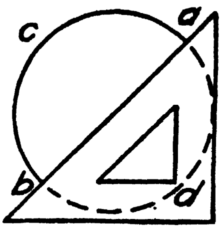


FIG. 140.

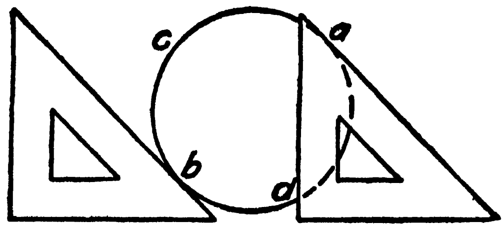


FIG. 141.

In Fig. 141 the triangle is used against the T-square with its edge slanting NW-SE. It marks the points *a* and *b*, not so accurately but well enough. This method applies also to noncircular cylinders and to cylinders whose centers are not known.

160. Tapered Shade Lines.—All shade lines applied to *straight* lines on the drawing are of uniform thickness. In the case of *curved* lines, if the shading ends, as at *a* and *b* of Figs. 140 and 141, on a continuous part of the curve, not at an angle of any kind, the shade line should die away gradually from its full width to that of a standard line.

Figs. 142 and 143 represent a thin washer or the end of a piece of pipe; mathematically, a solid cylinder with a hollow cylinder cut in it. In Fig. 142 the 45° triangle has been used to determine points *a, b, f* and *e* where shade lines must taper off to nothing. Rather exaggerated shade lines are shown for emphasis, the correct shade line not exceeding the standard line by more than 0".01. Notice that the excess of line over the standard is off the piece which casts the shadow, to obey the rule already given.

161. Shading Circles by Shifting the Center.—One method of applying shade lines to circles is suggested in Fig. 143. Move the center C to C' on the NW-SE line as near to C as you well can without danger of slipping back into the old hole. With C' as center and the same radius as before draw arcs from b and a towards the SE. They will increase the line in thickness, and as soon as a shade line width appears they are terminated. Return to the old center C, increase the compass setting and fill in the rest of the shade line of a uniform width. The effect is as shown in Fig. 142.

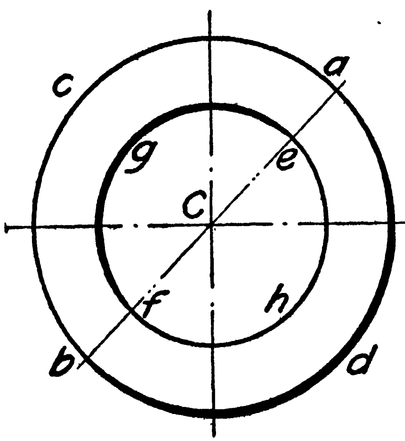


FIG. 142.

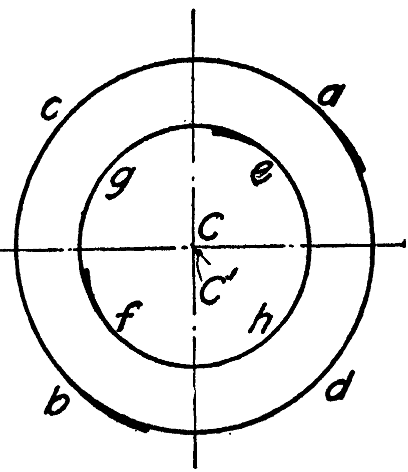


FIG. 143.

If CC' can be made exactly 0".01 in size the circle can be shaded by drawing a new semicircle from a to b, with center at C', leaving the setting of the compass at that for the standard line as it was.

This applies equally to the shading of the interior of the pipe. A new semicircle from f to e, with center at C', will give the shading shown in Fig. 142 but of the correct, not exaggerated, intensity.

If CC' exceeds 0".01 use C' only to make curved wedges as shown (exaggerated) in Fig. 143. Return to the center C to fill in the rest of the shade lines to the correct thickness of 0".025.

Fig. 144 is the section of a solid whose contours are partly curved, partly straight. From centers *m* and *n* 45° lines determine the die-away points of the shade lines. The rest is simple.

162. Shading Circles by Springing the Bow Pen.—The circles which are drawn with the bow pen are shaded by another method. It is a much quicker one when once the knack is caught.

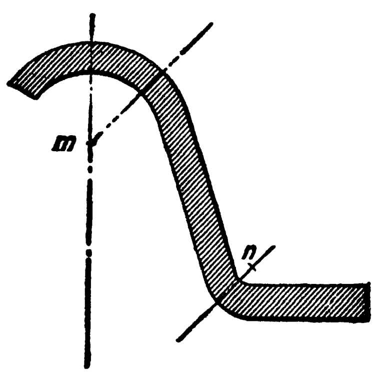


FIG. 144.

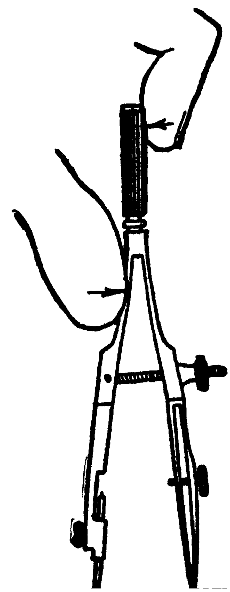


FIG. 145.

In this method no new center is used, but one must move from one's ordinary position in front of the drawing board and take a stand at the extreme NW corner. Hold the pen in a new manner. Instead of twirling the bow pen by the fingers, touching only the handle, put the ball of the thumb quite down on the needle leg and hook the forefinger over the tip of the handle as shown in Fig. 145. With the needle in the paper, a pressure on the thumb will be seen to press the ink point out, enlarging the radius. A very moderate

pressure is enough to add 0″.01 to the radius. This pressure takes effect only when the pen point is in the natural position to feel the pressure. By standing in the NW corner the pressure will naturally be towards the SE. Under these circumstances if you begin to reink the circle from *a* to *b*, clockwise, the shade line will be seen to start gradually at *a*, to reach its maximum at the right place and to die away at *b*. **Be sure to stand at the NW corner of the drawing board.**

The pressure needed is slight, and its effect soon learned.

163. Knowledge of Shading Useful in Reading Drawings.—Shading often saves much time otherwise used in looking from view to view to identify shapes and to determine which lines show projections and which show depressions.

In Part III of this book we will see that "detail drawings" (drawings of single pieces) as a rule should not be shaded; that "assembly drawings" (drawings of many pieces in contact) are often greatly improved by shading; and that textbook illustrations, in which one view is expected to depict a machine sufficiently for study of its action, rely on shading to give some idea of "depth" or thickness of parts, without which the student would be at a loss.

Shade lines used sparingly are valuable. Too many are harmful.

164. Application of Shading to Squares 6, 7, 9 and 11 (Pages 143, 144, 146, 149).—Shading must often be applied to drawings already inked without shading. Squares 6, 7, 9 and 11 are shown inked but not shaded. It is a good exercise to shade them by increasing the existing lines from a thickness of 0″.015 to 0″.025. This increase of thickness must be to the south or east of the existing line and, as stated, off the solid. Many draftsmen keep the pen set to a standard line and increase the thickness by eye.

Even if a student has no opportunity to draw these particular squares, and to ink them, and then actually to shade them, he can apply the principles of shading, mentally, to them, and mark lines to be shaded in pencil in his book.

When shading over a pencil drawing the shading becomes a part of the regular inking and the adjustment of the pen creates the correct thickness without judgment by eye. It is a more accurate process.

165. Line Shading, not Shade Lining.—A system of shading once very widely used is known as line shading. It is shown in the figures below as applied to suggest the roundness of cylinders and spheres.

In Fig. 146 and in Squares 35-38, pages 176-179, lines equally spaced but of varying width are used.

For flat surfaces uniform lines similar to hatching are used but, unlike hatching, the lines are parallel to a long edge of the area

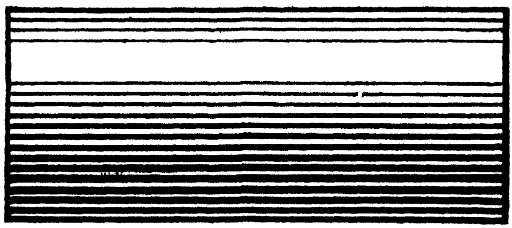


FIG. 146.

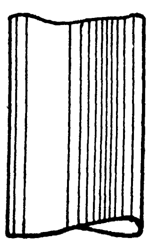


FIG. 147.

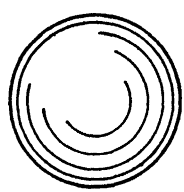


FIG. 148.

shaded. See Fig. 2, page 209. The width of line used is varied to suggest different degrees of illumination.

This system has been superseded by photography in advertising, where once it was widely used. It is now only a useful drill in the use of the right line pen showing its possibilities.

Another system of line shading uses fine lines unequally spaced to suggest rounding. Fig. 147 represents a cylinder and Fig. 148 a sphere. These shadings are still seen in use, occasionally, when draftsmen fear that rounded sections, if not shaded, would be mistaken for square ones.

CHAPTER XII

TRACING, BLUEPRINTING AND PHOTO-REPRODUCTION

166. Tracing.—Drawings must often be reproduced in large or small quantities. The old standard practice was in three steps. (1) Make the drawing on opaque paper with hard pencil as usual. (2) Over the drawing pin a sheet of smooth transparent *tracing cloth,* or a cheaper equivalent, *tracing paper,* and on it make an inked copy of the drawing under it. (3) Print photographically from the tracing as often as desired. The tracing was considered the master copy and kept for record and for future use.

Later steps 1 and 2 were combined by making the original drawing on a high-grade tracing paper, called *velum* paper, using H pencil to produce deep lines, black enough to be printed from, without doing the work again in ink.

167. Blueprint Paper.—The actual printing is generally performed by an arc-light blueprint machine. The gist of the process is to pass the tracing with a piece of sensitized paper under it, at a speed determined by previous trial, before powerful arc lamps which quickly darken the sensitive paper.

The paper is then washed to remove parts not darkened by the light. The result is a copy of the tracing in white lines on a blue field.

168. Brownprint Paper.—This is another form of paper handled much as blueprint paper is. It is expensive and not much used simply as a substitute. It is much used, however, to make brownprint negatives. In that case the tracing is run under the arc lights face down so the print produced is turned left for right like a true negative. This print has white lines on a dark brown field. From it another reversed print is taken. This time on blueprint paper. The net result is a print showing blue lines on a white ground. For producing a great number of prints the standard method is to make enough brownprint negatives to repeat as fast as the machine can run. The printing then becomes a continuous operation with no stops whatever.

The Navy Department furnishes its vessels with brownprints of the machinery. Since they are on rather thin paper, prints can

be taken from them for enclosing in correspondence when suggesting alterations or describing defects.

Prints from brownprint positives are not so sharp as those from brownprint negatives.

The Tables of Standards, pages 539-559, imitate blueprints from brown negatives.

169. Preparation of a Pencil Drawing for Tracing.—The tracing cloth is not completely transparent. In order to save the eyes, a pencil drawing for tracing should be very distinct. If necessary, faint pencil lines must be intensified before tracing. It is particularly necessary, if the drawing is on coordinate paper, that the pencil lines stand out clearly from the lines of the ruling. This is one reason for drawing with a 2H, when drawing over ruled lines. Examine your drawing, and make good any part which is too faint for tracing before applying the tracing cloth.

For another good reason, also, the pencil drawing, ready for tracing, should be a well-finished one. Errors in inking on tracing cloth can be corrected only by the exercise of care and skill. It is well, therefore, to have all excess lines erased, save very short extensions, and to have a clear distinction between full and broken lines.

Go over the centers of all circular arcs, including fillets, no matter however small they may be, and prick them with a small-sized needle point, such as that in the bow pencil, shoving it home till the shoulder hits the paper. The center can now be seen through the tracing cloth, and a great saving in time will result.

170. Applying and Preparing the Tracing Cloth.—The tracing cloth issued is applied over the drawing and thumb-tacked in place.

The question now arises, which side of the cloth should face up. One side will be seen to be highly polished and shiny, and the other somewhat duller. Draftsmen use either side, according to circumstances. The very shiny side is that originally intended for use. Ink lines on it have a sharper edge than those on the dull side, and erasure is easier. Professionals generally use the dull side. If future additions are needed it takes a No. 2 pencil.

Generally, the cloth has a surface which repels ink. To remove this greasy film, a little prepared chalk, called pounce, is dusted on and is rubbed in with a cloth or with the palm of the hand. A very

old chalk eraser from a section room will serve as well. When the excess chalk has been dusted off, the cloth will take ink well.

171. Procedure in Tracing.—The order of executing the ink work is fully covered by Fig. 137, on page 123, and the text on the opposite page. **Confine the application of this procedure to so much of the tracing as you expect to finish at one session.** Do not ink the circles for an entire sheet when you can finish only part of it. Tracing cloth changes with the atmospheric conditions, so that, on taking up the work again, many of the circles will be found to have shifted from their centers. Therefore, start only the views which can be inked completely during the drawing period. Be careful not to let the fine lines become too fine. If over-exposed to the light, very fine lines are lost on the blueprint, by reason of diffusion of light.

172. Correcting Errors.—Errors may occur, of course. In fact, they will occur despite our best efforts. Misplaced ink gives trouble.

A fine ink line may be erased with the green or emerald rubber alone. A heavy one needs the use of the gritty, or typewriter rubber. Do not use a knife, if work is to be done over the erasure, except to start erasing a heavily crusted shade line, and then use it lightly. If the erasure does not show the threads of the cloth, a new line may be safely drawn over it. One must watch carefully, however, for most erasures made by novices bare the threads somewhere.

If threads are bared, they must be covered with soap stone. Rub on the soap stone, or with a knife scrape a little powdered soap stone over the place and rub it in with a finger. When the spot is covered with soap stone, polish it by rubbing briskly with the back of a finger nail. The cloth is now ready for new ink lines without danger of ink running into the threads.

The commonest error made is in the drawing of a full line instead of a broken one. If this should occur, erase small gaps with a very sharp knife, or erase the entire line with a rubber eraser. It is not necessary to erase all trace of the original line. A little discoloration of the tracing cloth does not print, and quite a little remnant of an old ink line, which would show clearly if printed alone, will be quite invisible when it exists only in the little gaps of a broken line.

Small errors of excess line; when no reinking is required after

the erasure, may be removed by the use of an exceedingly sharp knife. The knife must be so sharp that one sidewise scraping motion will remove the projection. Sharpen the knife on the Arkansas oilstone, and strop it slightly on the crocus paper side of the pencil sharpening pad. It requires but a moment to restore a good edge to the blade, unless it has been abused greatly.

172-B Photographic Reproduction of Drawings.—Large engineering work requires large drawings for accuracy, but tracings and blueprints from large drawings are inaccurate from atmospheric causes and are cumbersome to file. Prints must be folded and are easily torn when handled in shops.

Many large firms follow the practice of photographing large drawings *to a small size,* and issue for shop use compact durable prints. Since the scale of reduction is rarely an exact fraction of the original size our usual reduced scales cannot be used, and all dimensions must be recorded. All lines and letters must be as clear as those on pages 36 and 69.

To meet the demand for great accuracy and speed in producing airplanes, due to World War II, six of the major aircraft companies, under the leadership of the near-by great plant, have very recently adopted a new practice as follows:

(1) Drawings are made almost exclusively *full size, in pencil only, on stiff aluminum sheets,* coated with dull-finish white or pale green paint. Sheets may be as large as 5 feet by 12 feet and if necessary put edge to edge for any larger size. No dimensions are recorded on the drawings.

(2) A huge camera, permanently set up, with many labor-saving accessories, photographs drawings on negatives of 20″ x 24″. Original drawings and negatives are filed for record and future use.

(3) The same camera enlarges negatives to *full size again* and prints as many copies as are needed on similar metal sheets, painted and sensitized for the bromide print process.

(4) The metal-backed prints are used in the shops for verifying the work by contact, and for constructing jigs, templates, etc.

This process has many advantages. The stiff sheets keep their size permanently. Reduced prints for instruction pamphlets or model-making are quickly produced. The absence of recorded dimensions keeps drawings legible. Original drawings and prints are as easily corrected as any pencil drawings.

CHAPTER XIII

SQUARES FOR FIRST DRAWING SHEETS

173. Squares for Selection for First Sheets.—In this chapter are 38 3″ squares and one rectangle which takes the place of two adjacent squares and the space between them. This is virtually 40 squares and, if all were assigned, would make four sheets.

Three sheets, or 30 squares, are usually assigned; less if time is short.

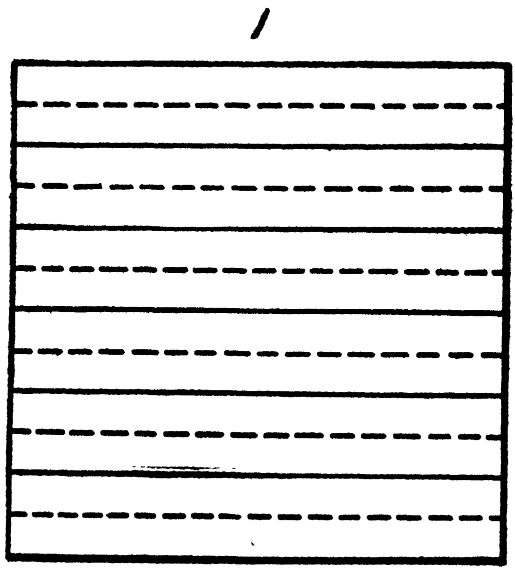
The first squares use straight lines only. If a sheet is composed only of such squares the proper title for it is STRAIGHT LINE DRAWING.

A second group of squares employs curved lines chiefly. An appropriate title is CURVED LINE DRAWING.

A third group, 21-30, is devoted primarily to practicing some geometrical processes which draftsmen may be called upon to use. Such a sheet can be titled GEOMETRICAL DRAWING.

174. Terminology for the Squares.—In describing the work to be put in each square, we frequently refer to its center and to the horizontal and vertical center lines. Where these lines cut the sides of the square we have four points which we refer to in terms borrowed from the use of maps. These four points are then called N, W, S, and E, reckoning distances from the center. In the same way the four corners are called NE, SE, SW, and NW. The diagonals are NW-SE and SW-NE. The ends are given in the order natural for drawing the lines. Thus, NW-SE is drawn from NW to SE.

Square 1. Full and Broken Standard Lines.



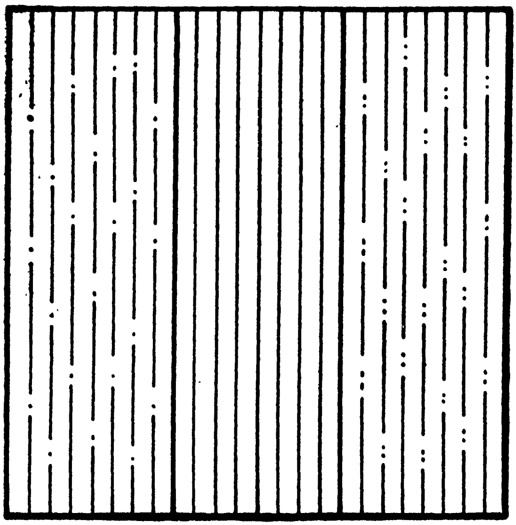
This square illustrates the lines to be used **for visible and concealed edges of tangible objects.** They are the "standard lines" of Fig. 44. The figure above shows the final, or inked drawing. It is a meaningless figure, designed only to practise making samples of these lines.

Lay off $\frac{1}{4}''$ spaces along the left edge of the square. Draw the horizontal pencil lines as full clear lines alternating with faint full lines on which emphatic points have been impressed as shown in Fig. 96 of page 85. The pencil lines exceed the width of the square, slightly.

Fix it in mind for future use that when drawing tangible objects the actual edges are shown by these bold "standard" or "heavy" lines, continuous for visible edges, and "broken" or "dotted" for hidden edges. Remember also that in practice many hidden edges are not shown at all, and if there are many lines close together their thickness may be reduced to "medium" lines, 0.″010 thick, *by screwing up the pen 45°.*

Square 2. "Imaginary Lines."

2



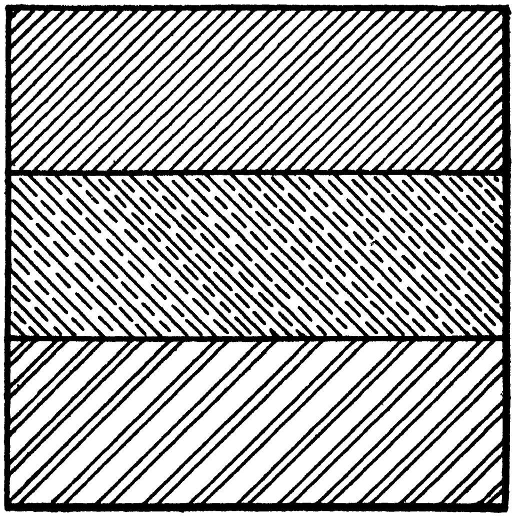
Lines 9 to 14 of the Alphabet of Lines, Fig. 44 of page 36, do not represent actual edges of an object and cannot be seen by examining it. They are lines added to satisfy some mental need, to help realize some geometrical fact, and are therefore called "imaginary" lines. They are also called "fine" lines because when ruled in ink are specified as only 0.″005 thick.

Square 2 is divided by standard lines into three vertical panels, each 1″ wide. The first panel is filled with "center lines" (No. 9 of the Alphabet). The second panel is filled with fine full lines such as are used for "dimension" lines (No. 10) or "axes of projection" as used in descriptive geometry (No. 11). The third is filled with "construction lines" (No. 12).

Lay the 32 scale along the south edge of the square and mark off ⅛″ spaces from SW to SE. Pencil the lines as they appear above, emphasizing those at the 1″ spaces.

Square 3. Lines Used for Hatching.

3

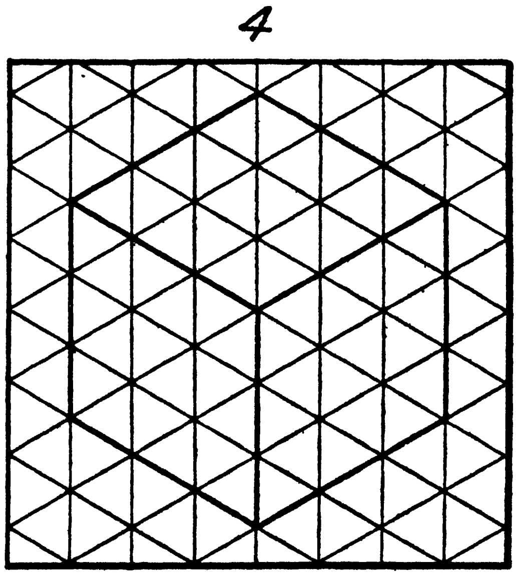


This square is divided by standard lines into three 1″ panels. In drawing one often represents a piece of machinery as cut open, so as to expose the interior. Such a cut, which is not to be actually machined, is marked as an imaginary cut by hatching the area. The purpose will appear later. At present we merely practice three different styles which conventionally represent three metals, cast iron, brass (or any copper alloy), and steel.

In pencilling the hatching remember three points. *First.* The spacing is not measured but is judged entirely by eye. *Second.* The spacing should not be closer than 1/16″, as shown above. If closer spacing is attempted it is almost impossible to keep a glaring streakiness out of the hatching. *Third.* Do not complete hatching in pencil. Draw only enough lines to indicate the angle and style. Leave the completion to the ink work.

In this case rule a dozen lines in the NW corner of the first or top panel. Then a dozen in the NE corner of the middle panel. Finally a few pairs of lines in the NW corner of the third panel.

Square 4. Corner View of a Cube on Isometric Ruling.

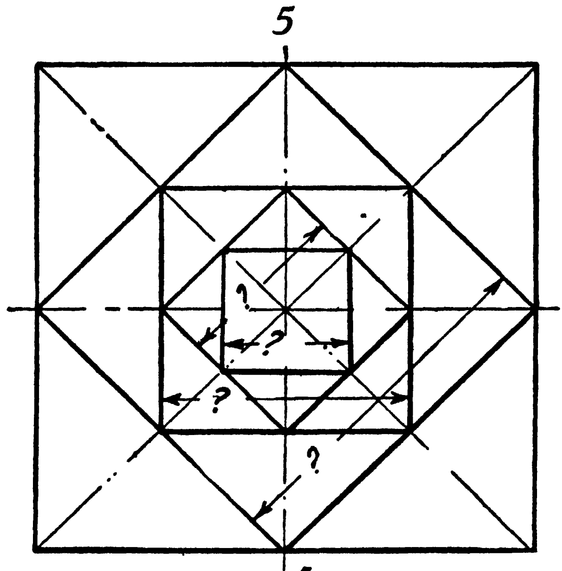


Isometric ruling is a network of equilateral triangles, as shown. To produce it scrupulous accuracy is needed.

Divide the south edge of the square into $\frac{3}{8}''$ spaces, by the scale, and draw vertical lines through the points. Set the triangle as in Fig. 74, p. 60, and draw 30° lines from the intersections of the odd numbered interior vertical lines with the bottom edge of the square. Set the triangle as in Fig. 75, p. 60, and draw lines sloping the other way through the same points and also through points of intersection of the first 30° lines with the east side of the square. Return to the position of Fig. 74 and complete the first set of 30° lines by means of intersections along the west side of the square. Reverse again and complete the other set of 30° lines. The north edge of the square does *not* pass through points of intersection of the isometric ruling.

Emphasize some of the lines by pressure on the pencil so as to bring into view a hexagon and three interior lines to represent the corner view of a cube.

Square 5. Inscribed Squares.



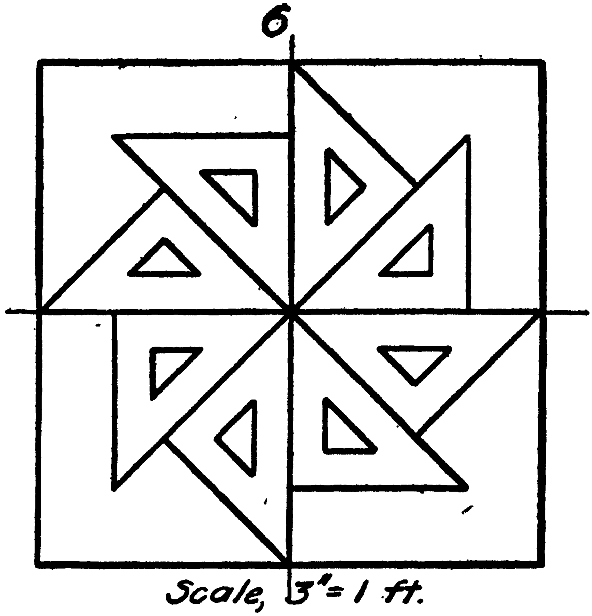
This figure may be taken to represent, on the scale of 4″ = 1 foot, a pile of square blocks, diminishing in size, and piled with each one turned 45° to that on which it rests.

There are five squares in all, counting the outer 3″ square as the first.

In pencilling, nothing more is needed than the 45° triangle and the T-square, to guide the pencil, and strict accuracy in placing the lines.

Measure dimensions to the scale, 4 inches = 1 foot, and record them in the places indicated in the figure by interrogation marks.

Square 6. 45° Triangles.



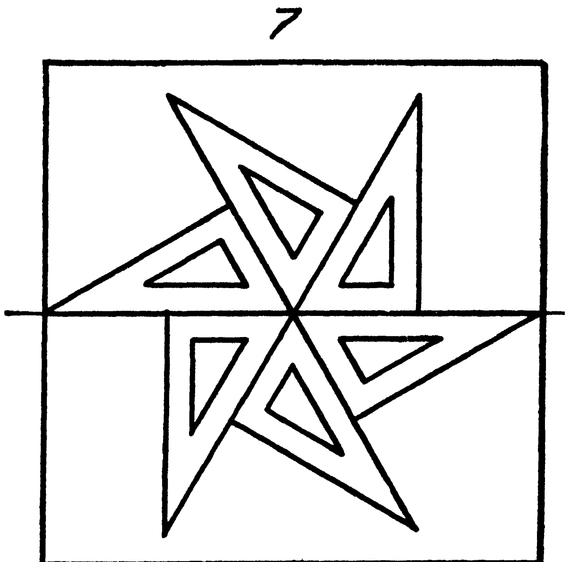
Eight 45° triangles are here shown arranged in a pattern with corners touching at the center, C. The scale is marked as 3″ = 1 foot.

Find C by the diagonals. On each diagonal mark off a distance of 6″ from C. These points, with N, E, S and W, are the eight outside corners of the triangles. It is easy to construct from them the outlines of the triangles.

The distance from the triangular openings to the triangular outline is everywhere 7/8″. To apply this dimension 24 times in all, follow Art. 115, at bottom of p. 86.

The accuracy of a figure of this kind, in which a center plays a very prominent rôle, will depend chiefly on the **accuracy of the lines which pass through that center.** Such initial lines are the foundation on which all the rest are built, and extreme care must be taken over them. This remark will apply to many of the 3″ squares, and to many future drawings.

Square 7. 30° Triangles.



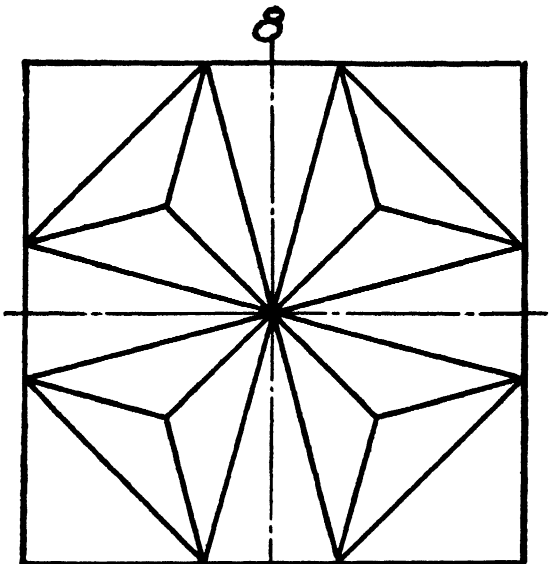
Scale, $1\frac{1}{2}'' = 1$ ft.

This drawing represents six 60° triangles, touching each other at the center of the figure. The scale is $1\frac{1}{2}'' = 1$ foot, and the triangles have their hypotenuses 12″ in length. The distance from the sides of the triangular opening to the parallel outer edges is everywhere $1\frac{1}{4}''$.

Find C by the diagonals. Draw the H. C. L. and two 60° lines through C. Set the dividers to the distance CE and mark off this distance on the 60° lines in four directions from the center. These are the 30° points of four of the triangles.

With the 60° triangle against the T-square, in the positions of Figs. 72 to 75, p. 60, complete the outlines of the triangles. Set the bow pencil to the distance $1\frac{1}{4}''$, to scale, and, after testing on the waste margin, draw a circle, center at C, and draw six arcs whose centers are on the outer edges of the triangles. This again puts into operation the repeating of dimensions, of Art. 115. Suitable tangent lines complete the pencil work.

Square 8. Tetrahedrons.



Scale, full size.

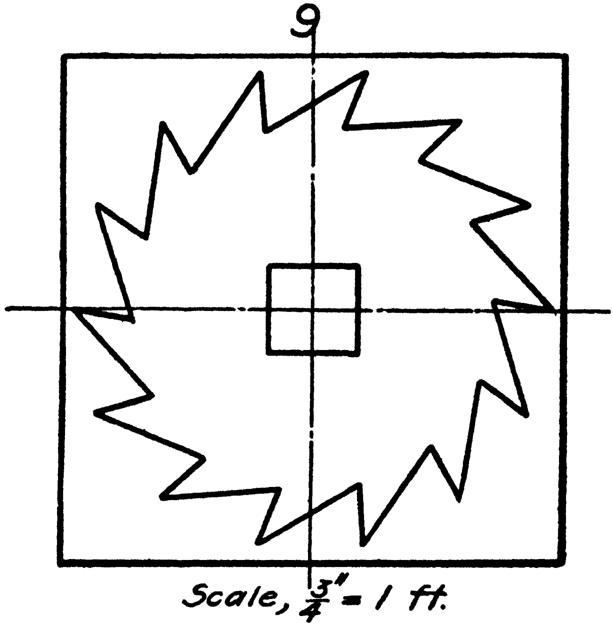
This figure may be taken to represent four regular tetrahedrons (triangular pyramids all of whose faces are equilateral triangles). Whatever it represents, its object is to practise passing 15° and 75° lines, as shown in Figs. 84 and 85 of p. 66.

Find C by the diagonals, and prick the point accurately. Draw the H. C. L. and the V. C. L. Now erase pencil lines around C so that the prick mark may be easily seen for locating further lines.

Draw lines at 15° and 75° through C, four in all. The feeling of the pencil, running over the prick mark C, insures the accuracy, as does the erasing of lines at C to increase the visibility. Accuracy is essential for this figure. Inaccuracy at a center of figure such as this one starts a series of increasing errors which spoil results and delay completion.

Four 45° lines near the corners of the square and eight more 15° and 75° lines, from the ends of these four, complete the figure.

Square 9. Ratchet Wheel.



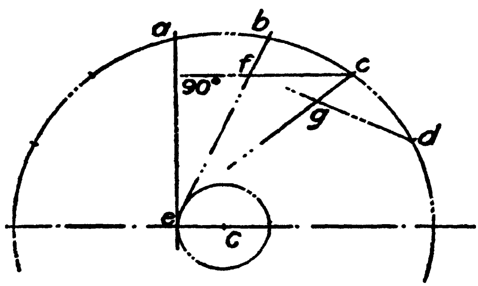
This is a ratchet wheel of 14 teeth, with a central square hole. It is drawn to the scale of 3/4″ = 1 foot, or one-sixteenth size.

The figure is of straight lines only but the location of the lines is based on circles and requires the use of the compass and dividers or spacer.

Find C by the diagonals. Draw the H.C.L. and V.C.L.

Study the scale marked 3/4 and set the compass to a radius of

23″ (or 1′–11″). Check the setting on the waste margin. With center at C, draw a circle in pencil. Set the bow spacer to 3½″ radius and draw a second circle. This work is shown here.



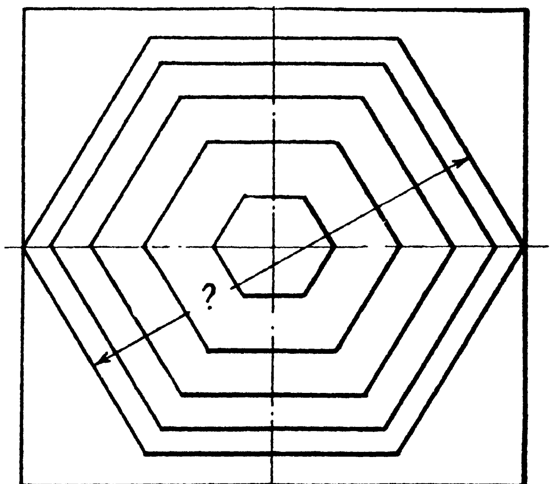
Divide the semicircle from *w* to *e* (points close to W and E) into seven equal parts by stepping with the dividers as in Fig. 100 of Art. 116, p. 88. Assuming the subdivision complete we have the points *a, b, c, d,* etc., above. From these points draw tangents to the small circle, at least draw the outer ends, as *fb, gc.* These lines are the faces of the teeth of the ratchet wheel.

To draw the backs of the teeth draw lines from the points of the teeth each one perpendicular to the face of the tooth two spaces behind it. Thus *cf* is drawn perpendicular to *ae,* and *dg* perpendicular to *bf.* See Fig. 83, p. 65, for the method to use. To hasten matters, once *f* has been determined, a circle may be described with *C* as center and *Cf* as radius, thus locating all points such as *f* and *g,* in one operation.

The square hole in the centers is formed by horizontal and vertical tangents to the 7″ circle.

Square 10. Hexagons.

10

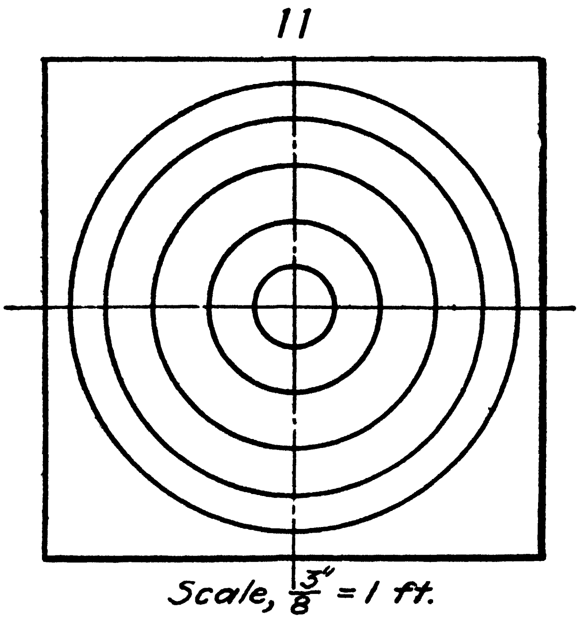


Scale, 3″ = 1 ft.

Find C by the diagonals and draw the H.C.L. and the V.C.L. From W draw a 60° line. With center at C draw a circle tangent to this 60° line. Complete the outside hexagon by passing 60° and horizontal lines tangent to the circle. Measure this hexagon across the flats to the scale of 3″=1 foot.

To the same scale describe circles whose diameters are 9¼″, 7⅝″, 5¼″, and 2½″, and pass tangent lines about them to form the smaller parallel hexagons.

Square 11. Circles.

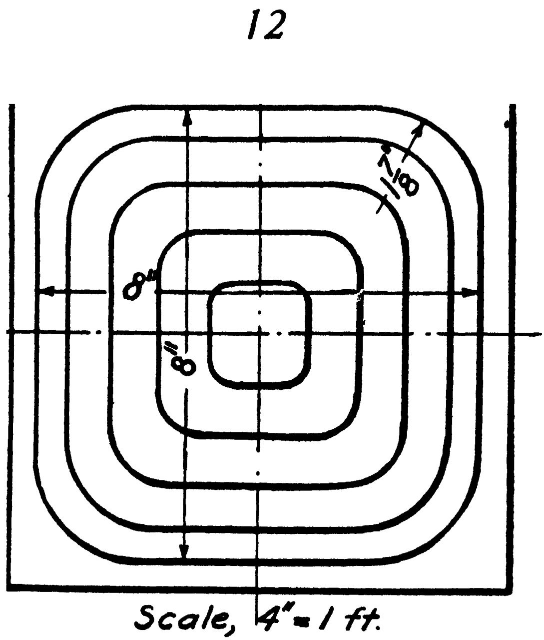


The scale is $\frac{3}{8}''=1$ foot. Circles of various sizes form the subject matter of the square. Circles are quoted by mechanics, by their diameters, not their radii. The draftsman sets his compass to the radius but he tests the circle drawn by measuring the diameter.

Find C by the faint crossing mark of two diagonals. Draw H.C.L. and V.C.L. Use the compass to describe circles of 7′–2″, and 6′–1″. See Art. 22, p. 12. Be sure to have the legs of the instrument perpendicular to the paper. Do not force the needle in to the shoulder unless it has been ground down to the size of that of the bow pencil. See Fig. 21, p. 16.

With bow pencil describe circles of 4′–7″, 2′–9″ and 15″. See that the lead of the bow pencil is sharpened as in Fig. 28, p. 19. Whenever a flattening across the end of the lead is noticed resharpen it, and after each sharpening readjust the needle to carry out Art. 37, p. 23.

Square 12. Fillets in Square Corners.



This figure of five squares with rounded corners gives practice in fitting a quadrant of a circle tangent to two straight lines.

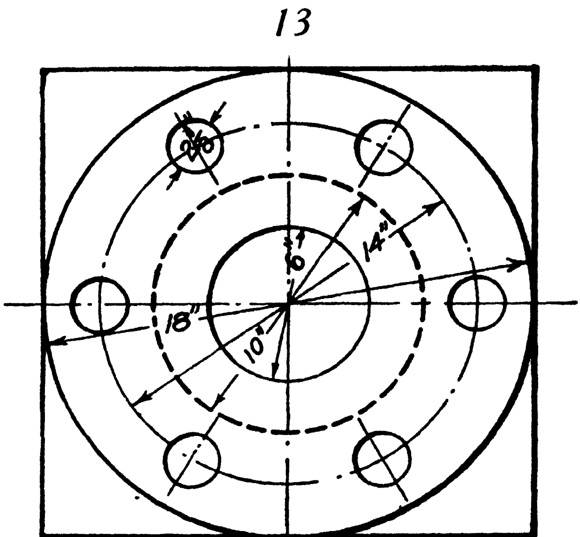
Such rounded corners are common on machinery and are called filleted corners. They may be projecting corners, rounded so as not to cut hands or material, or interior corners filled in to preserve strength by avoiding a sharp corner where a crack may easily start to form.

A dimension line of the present or "new standard" has but one gap in its length, that in which the actual size is inscribed. Each end has an arrowhead exactly touching the lines whose width apart is recorded. The exception is that when a *radius* is recorded, like the 1⅛" dimension above, no arrowhead is placed at the center. *Diameters,* like those on the preceding page, require two.

The scale of this figure is 4″=1 foot. Find C and draw H.C.L. and V.C.L. From C point off towards W distances of 7/8″, 1 3/4″, 2 5/8″, 3 3/8″ and 4″. Set one leg of the dividers at C and adjust the other leg in turn to fit each mark on CW. Use hair spring adjustment for accuracy. Transfer the marks on CW to CN, CE and CS by pricking points on those lines. "Square out" with these prick marks to form the five squares.

Set the bow pencil to the radius 1 7/8″, and round the corners of the largest square by the method of Art. 118, p. 90, the "full method." Set the bow pencil to a radius of 1 1/2″ for the second square and use the "abbreviated method." Continue with a radius of 1″ for the next square, then 11/16″, and finally 3/8″ for the smallest.

Square 13. Flanged End of Hollow Shaft.



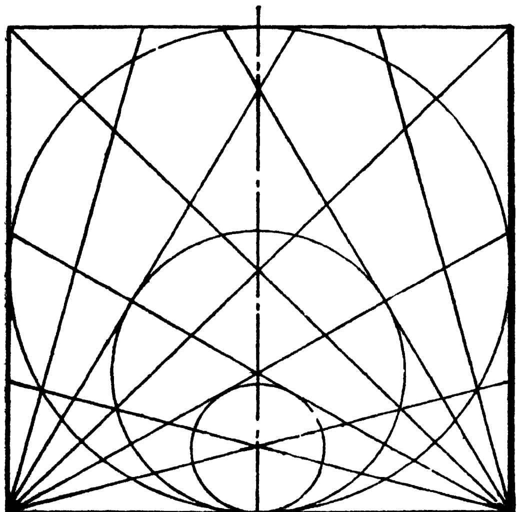
Scale, 2" = 1 ft.

This figure represents, to the scale of 2″=1 foot, a shaft of 10″ diameter with a 6″ bore hole, having an 18″ flange bored for six 2⅛″ bolts, evenly spaced on a "bolt circle" of 14″. It is a simplified form of the flanged coupling at the end of a length of shafting for the main engines of a large vessel.

As a drawing exercise it is simply a problem in the accurate handling of the compass and bow pencil.

Square 14. Tangent Circles.

14



Scale, $\frac{3}{4}$" = 1 ft.

The value of this square is as a test of accuracy.

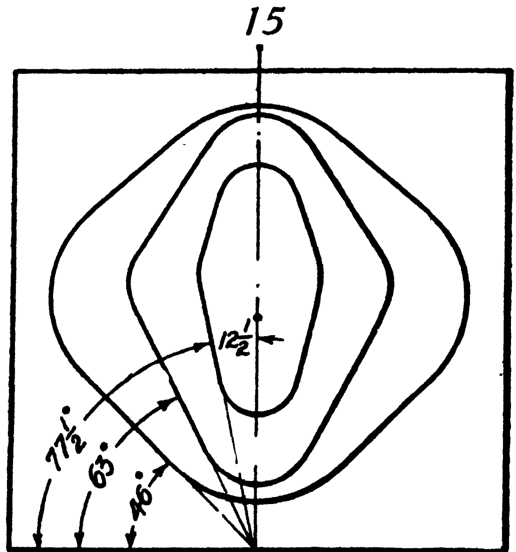
From SW and SE draw lines at 15°, 30°, 45°, 60° and 75° across the square. Prick points at SW and SE, accurately and carefully, and erase pencil lines about the points as often as necessary to be able to see the spots. Feel for the jog when the pencil crosses the prick mark. If all the lines have been seen and felt one can be assured of their accuracy.

The lines will intersect at four points on the V.C.L. Look for errors if an intersection falls to either side.

With the lower three of these intersections as centers describe circles tangent at S to the south edge of the square. It is well to prick this point and to be assured of accuracy by the feel of the pencil as it passes over it.

Measure the diameters of the three circles to the scale, ¾ inch = 1 foot, and record them by diametrical dimension lines in the SW-NE quadrants of the circles like those on the opposite page.

Square 15. Fillets in Odd Angles.



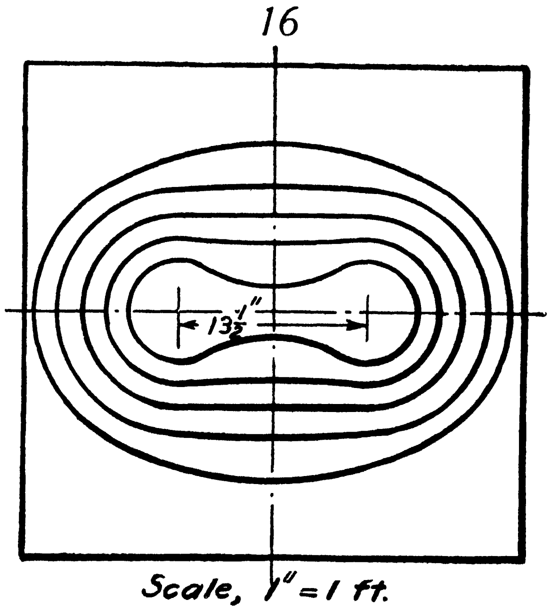
Scale, 2″ = 1 ft.

This figure calls for the use of the protractor and practices fitting fillets in angles other than right angles. The scale to be used is 2″=1 foot.

Find C and draw the V.C.L. Place the protractor with its center mark at S and its base line horizontal. Prick off angles of 46°, 63° and 77½° with the horizontal in both quadrants, right and left, thereby using the two systems of enumerating degrees, seen on the instrument, in turn. Join these points with S. Turn the protractor upside down, place the center mark at N and with base line horizontal and coinciding with the north edge of the square, lay off angles of 41°, 57½° and 73°, measuring down from the base line on both sides of the protractor. Join these points with N.

We now have three quadrilaterals with their N and S corners in common. Round the corners of these figures with fillets, the largest quadrilateral with a fillet of 3¼″ radius, the middle one with a 2″ fillet, and the smallest with a 1⅜″ fillet. Use the method of Art. 119, p. 91.

Square 16. Arcs Tangent to Arcs.



The scale to be used is 1" = 1 foot.

Find C and draw the H.C.L. and the V.C.L. From C lay off, to right and left, a distance of 6¾", to establish two centers. Describe from these centers five pairs of circular arcs, facing each other, the outer three to be semicircles, and the inner two rather more than semicircles. The radii must be 3½, 5, 6¾, 8¾ and 10½".

Connect the largest pair of arcs by convex arcs of 23¾" radius. Follow the method of Art. 120, page 93.

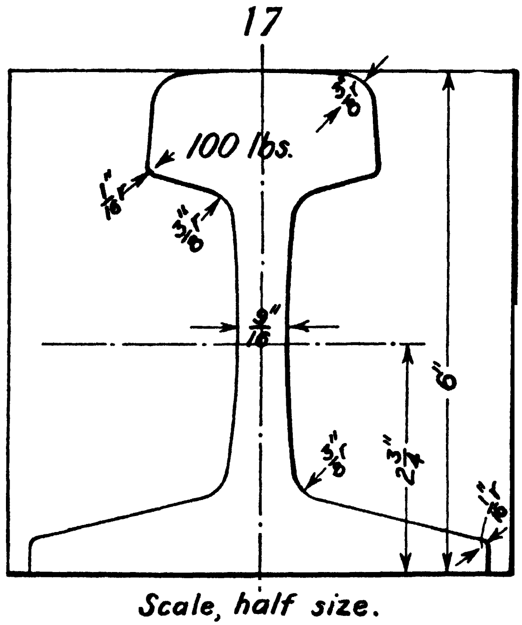
Connect the next largest pair by convex arcs of 7′–4¾" radius. This radius will necessitate the use of the extension bar. See Art. 126.

Connect the middle arcs by tangent straight lines.

Connect the fourth pair by concave arcs of 5′–3" radius. See Art. 120, Fig. 108, on page 94.

Connect the smallest arcs by concave arcs of 9¾" radius.

Square 17. Rail Section.

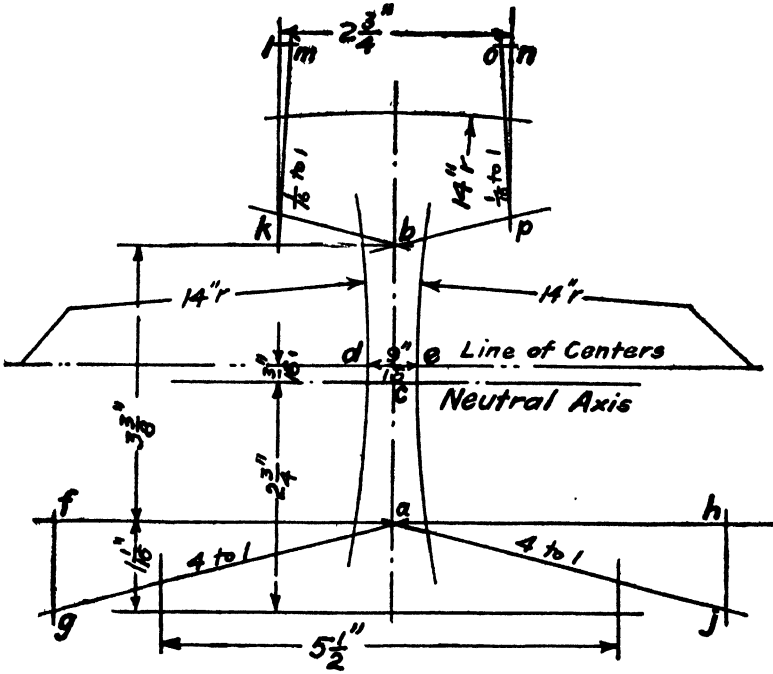


This figure represents an end or cross-section of a 100-lb rail drawn half size. Such a rail weighs 100 lbs. for each yard of length.

The three parts into which it is naturally divided are called the head, the web, and the base. The drawing shows a horizontal line inked as a center line, although the figure is not symmetrical above and below it. It is not even midway between. A rail is a beam, and when it bends due to the load, the weight on a wheel passing over it, the part above this line is compressed and that below is extended. At the line itself, which is called the "neutral axis," there is neither compression nor tension. It is thus seen to be a kind of scientific center line, and it is put on the drawing because the strength of the beam to resist bending depends upon this line's position.

There is no half-size scale on the triangular scale, so dimensions must be mentally bisected.

The pencil work for Square 17 is shown on this page.

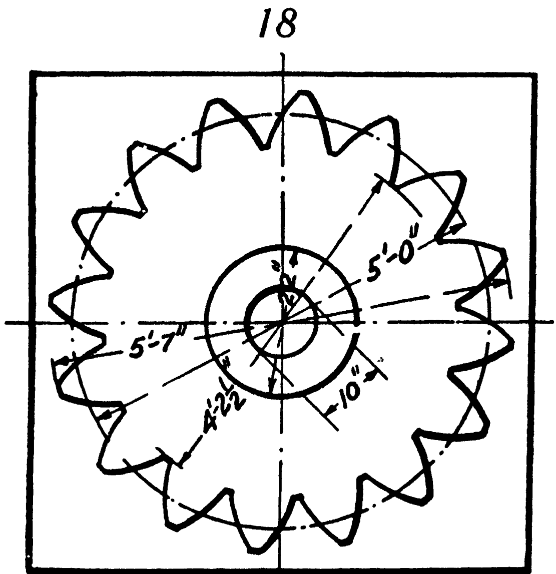


Six of the straight lines incline at angles given, not by degrees, but by the "slope ratio." Thus the top edges of the base are marked "4 to 1." The sides of the head are marked "1/16 to 1." Slopes are laid off by the use of any convenient scale, regardless of the scale of the drawing, and with any convenient units.

Thus to lay off the 4 to 1 slope from *a*, draw *fah* horizontal, and lay off four units, say ½" units, from *a*, to points *f* and *h*. Draw *fg* and *hj* vertical and measure one unit down from *f* and *h* to the points *g* and *j*. Join *g* and *j* to *a*.

Note that certain points, *a* and *b*, are important to the construction and are plotted on the V.C.L., by the dimensions given. In fact the letters are very much in the natural order in which they are utilized. Note that *bk* is parallel to *aj* and *bp* to *ag*. See p. 64.

Square 18. Conventional Drawing of a Gear Wheel.



Scale, ½" = 1 ft.

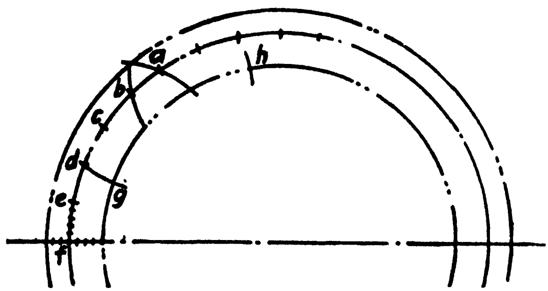
"Gear wheels" are circular wheels whose cylindrical surfaces have been given carefully shaped projections, or "teeth." The aim is to prevent slipping when one such wheel turns and "drives" another. They are considered as substitutes for smooth wheels which drive by friction alone, but which *are* subject to slipping and are not exact in their action. Gear wheels, therefore, have a theoretical size, that of the equivalent smooth "friction gear wheel." This size is called the "pitch" size, and the teeth are formed by adding projecting points beyond the pitch circle and by cutting notches within it into which the points of the teeth of the companion gear wheel fit.

The profiles, or driving faces of the teeth, are usually involute curves, very carefully cut by automatic machinery of a high class. In practical drawing we need only to *represent* the gear wheel, replacing the involute curves by circular arcs.

The pitch circles are put on the drawings of gear wheels, for, in

order to match them so that several shall be "in mesh" to transmit motion, the pitch circles must be drawn as tangent to each other. Gear wheels are, therefore, spoken of *by their pitch diameters* only.

The size of the teeth is the next item of prime importance. Gears, to mesh with each other, must have teeth of the same size. The size is regulated by the pitch or distance *along the pitch circle* from a point on one tooth to the corresponding point on the next tooth.

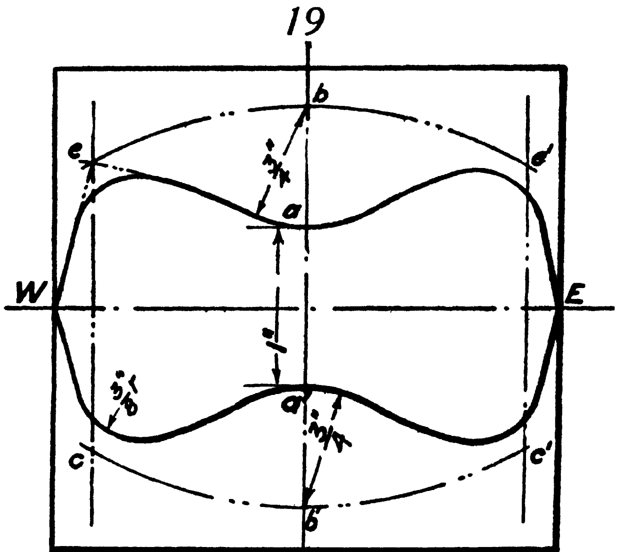


The figure above shows the beginning of the pencil work for Square 18, which represents a gear wheel of 16 teeth, drawn to the scale on which ½″ represents a foot. Proceed as follows: Find the center of the square and describe the pitch circle, 5′–0″ in diameter. Divide the entire circumference into half-pitch distances. In this case, divide into 32 equal parts, by first dividing into 45° arcs and then subdividing these into four parts. We now have the points *f, e, d,* etc. Any two of these distances represent the pitch, *fd, ec,* etc.

Divide any half-pitch distance, as *fe,* into fifths and step off four of these fifths from *f* towards *C,* and three from *f* away from *C.* Describe now the "addendum" and the "root" circles as shown.

Set the bow pencil to a distance equal to the chord of three half-pitch arcs, say from *a* to *d,* and from any such point as *a* strike an arc *dg* cutting the root circle at *g.* Reverse, and, with *g* as center, strike the arc through *a.* This will be the face of a tooth. From *b* strike in the other direction to find *h* the center of the back face through *b.* This completes one tooth. The same construction applied to *c* and *d* will form a second tooth, to *e* and *f* a third, etc.

Square 19. Standard Cement Test Block.



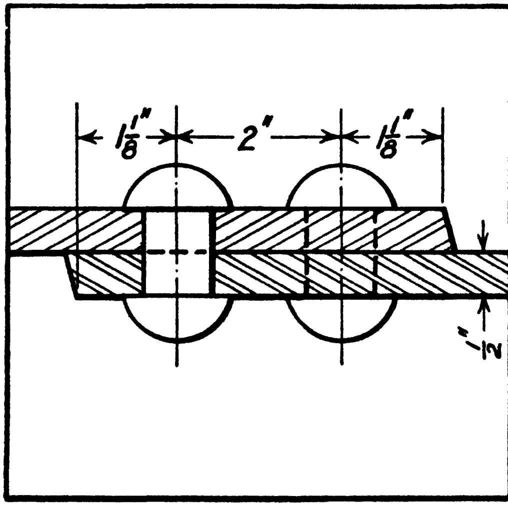
Scale, Full Size.

This figure represents the standard shape in which Portland cement is formed for testing its strength. The "briquette" is of the shape shown and is 1″ thick. The cross section of the neck is exactly 1 square inch. Jaws, with rollers at the gripping points, grasp the briquette at its enlarged ends. By a steady pull the briquette is subjected to tension until it breaks, and the pull necessary to break it measures its strength in pounds per sq. in.

To draw the outline we proceed as follows: First, plot the points *a* and *a′*, then *b* and *b′*. With *b* and *b′* as centers, describe arcs of 3/4″ radius through *a* and *a′*. Draw the lines *ce* and *c′e′*, parallel to the east and west sides of the square and two-tenths of an inch from them. With *b* as center and *bb′* as radius, draw an arc determining the points *c* and *c′*. Similarly, with *b′* as center, strike an arc determining the points *e* and *e′*. With *c, c′ e,* and *e′* as centers, and with a radius of 1 3/4″, draw arcs tangent to the arcs through *a* and *a′*. Join *We, Wc, Ee′* and *Ec′*. 3/8″ fillets in the outer corners complete the outline.

Square 20. Double-Riveted Lap Joint.

20

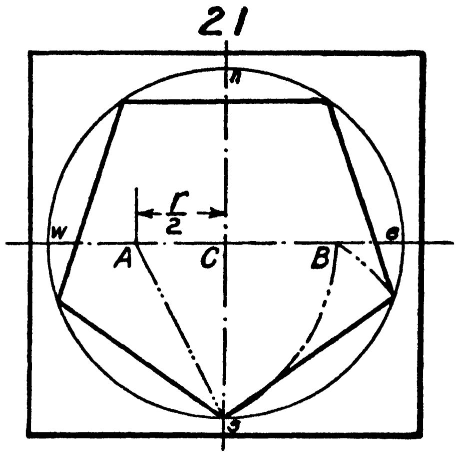


Scale, half size.

This figure shows two plates of steel, $\frac{1}{2}''$ thick, lapped and riveted together, with two rows of $\frac{3}{4}''$ rivets having "button" or "snap" heads and points. The rivet rows are $2''$ apart and are $1\frac{1}{8}''$ from the actual edges, which are beveled $\frac{1}{8}''$. The section is through one of the rivet holes but, following a standard drafting convention, the rivet itself is uncut. The other rivet is back of the plane of the section as the riveting is "staggered" or zig-zag riveting. The round head is part of a sphere of $1\frac{3}{16}''$ diameter, but is not quite a hemisphere, being only $\frac{1}{2}''$ high. This means that the center of the sphere is $\frac{3}{32}''$ below the outer surface of the plate, or $\frac{3}{64}''$ on the half scale drawing. The rivet, though called a $\frac{3}{4}''$ rivet, was enlarged to $\frac{13}{16}''$ by the squeezing it received when "closed." Rivet holes are always drilled to $\frac{1}{16}''$ larger than the original or "nominal" sizes of the rivets to be put in them.

Pencil all outlines but omit the hatching except a few lines to show the slope and character of hatching.

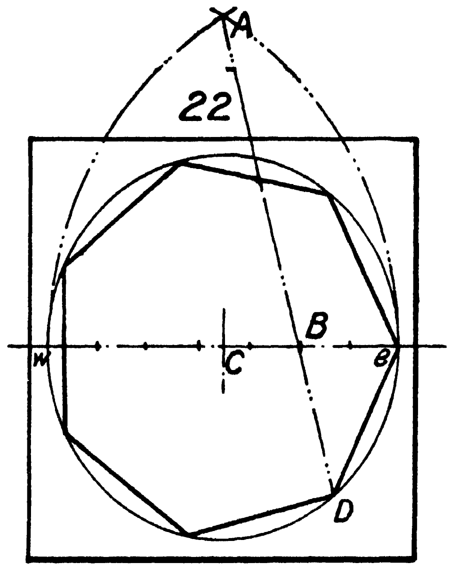
Square 21. Pentagon.



In this square a circle of 2¾″ diameter is centered at *C*. Its diameters are lettered *wCe* and *nCs*. The problem is to inscribe in it a regular pentagon.

Bisect a radius, as *wC*, at *A*. With *A* as center and *As* as radius swing an arc, *sB*, cutting *Ce* at *B*. The chord *sB* is the length of side of the pentagon, and may be used to step around the circumference in five steps, starting at any desired point. The figure shows *s* used as a starting point or corner of the pentagon.

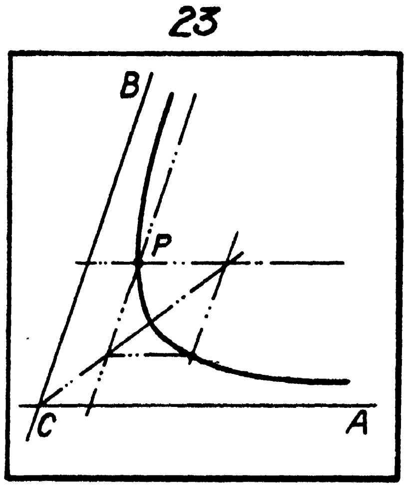
Square 22. Polygon on *n* Sides.



In this square a circle of $2\frac{3}{4}''$ diameter, center at C, is to have a regular polygon of seven sides inscribed in it. Any number other than 7 might have been used, instead, however.

Divide the diameter, *we*, into 7 equal parts, say by the geometrical process of Fig. 99, page 88. Find A, the vertex of an equilateral triangle of which *we* is the base. Mark the point B, two spaces from e (or from w, if preferred). Join AB and extend AB to D, a point on the circumference of the circle. The chord distance De is the length of side of the regular heptagon required. It will step around the circle in seven steps with a high degree of accuracy, though, mathematically, the process is an approximation. The value is theoretical rather than practical, since a good draftsman can save time using the trial and error method of Fig. 100, page 88, instead.

Square 23. Hyperbola.

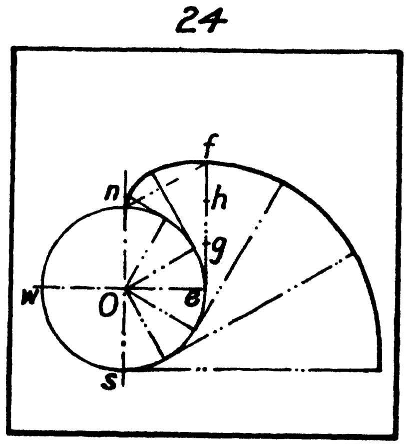


The problem here is to describe a hyperbola, having as given a pair of lines, to act as asymptotes, and one point on the curve itself.

The asymptotes given for this particular case are the lines *CA* and *CB* including an angle of 70°. *C* is ½″ from the south edge of the square and ¼″ from the west edge. *P*, the given point, is 1½″ from the south edge and 1″ from the west edge. Follow the method of Art. 135, page 105.

Fair the curve and mark the limits of the contours of the frosted curves used in pencil, for repetition in inking. See Fig. 124, page 103. Also mark the curves used with identifying letters such as *A* on Figs. 124, 125, and 126, page 103. Mark the curves on the drawing with the same letters, as was shown on Fig. 123, where the letter *A* is seen to the left of the V.C.L. If old marks, now obsolete, are found on the curves, erase them. Keep new marks on until the drawing has been inked.

Square 24. Involute of a Circle.

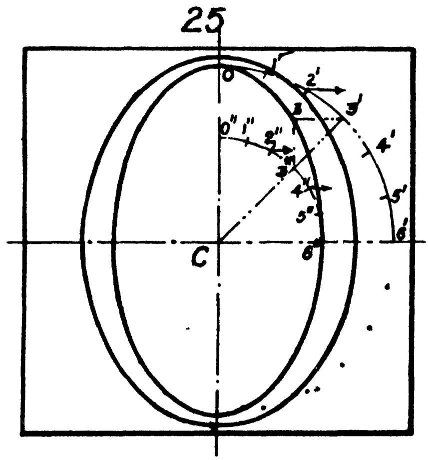


Imagine a cord wound tightly around a drum or cylinder. Begin to unwind it, keeping it taut as you do so. Your hand would describe a curve known as the involute of a circle. The involute has great importance in engineering as the best curve for the face of the tooth of a gear wheel.

The specific problem here is to describe the involute of a $1\frac{1}{4}''$ circle, center at O, $\frac{7}{8}''$ from the west edge of the square and $1\frac{1}{8}''$ from the south edge. The top point of the circle, n, is the starting point of the involute and the semicircle to the right is to be unwound. Points corresponding to successive unwrapping of 30° arcs will be sufficient, and a smooth curve passed through them.

Find ef, equal to en, the quadrant of the circle, by the method of Art. 128, page 100. Trisect ef at g and h. Divide the quadrant en into 30° arcs by radii at 30° angles, and divide the quadrant es in the same way. At the end of each radius draw a tangent upward. At s draw it to the right. On each tangent lay off a distance equal to the arc from n to that point. These distances will be from 1 to 6 units of the magnitude of eg and are taken by dividers from the line ef. Pass a smooth curve from n through these end points.

Square 25. Exact and Approximate Ellipses.

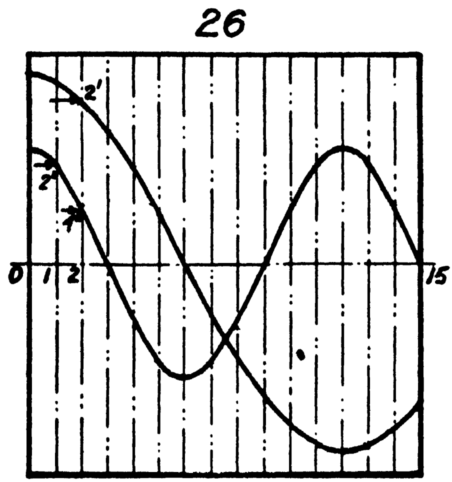


This figure is virtually a large letter *O* of pleasing shape.

The outer ellipse is a *draftsman's ellipse,* center at *C,* major axis vertical, measuring $2\frac{7}{8}''$, and minor axis horizontal, measuring $2\frac{1}{8}''$. Follow the method of Art. 130, page 102.

The inner ellipse is an *exact ellipse,* center at *C,* major axis vertical, measuring $2\frac{3}{4}''$, and minor axis horizontal, measuring $1\frac{5}{8}''$. Follow the method of Arts. 131 and 132, page 103, using 15° subdivisions of the circles. Prick the points 0, 1′, 2′, . . . 12′, and 0″, 2″, 4″, 6″ . . . 12″ for use in the next square, also.

Square 26. Sinusoids.



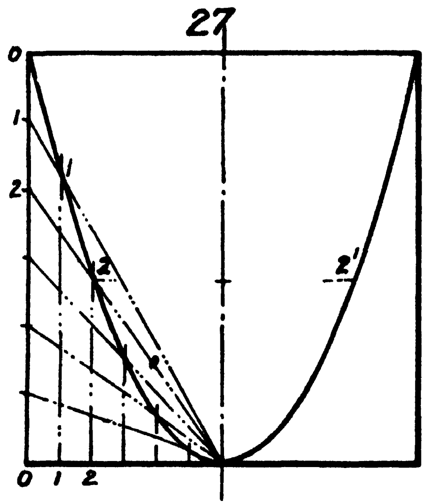
This square puts into practice the processes described in Arts. 133 and 134.

Draw the H.C.L. of the square and divide it into 15 spaces of 0.″2 each by means of the decimal full-size scale. Erect verticals at the points of division, and number them from 1 to 15, the point *W* acting as the zero point and *E* as point *15*.

Use the 2¾″ circle of Square 25 for the large sinusoid, and project horizontally from points 0, 1′, 2′, etc., to vertical lines 0, 1, 2, etc., of this square. Five-eighths of a complete periodic curve will be thus plotted. Sketch and then fair the line through the plotted points.

Plot a small sinusoid, projecting from the points 0″, 2″, 4″, etc., of the 1⅝″ circle of Square 25, omitting all odd-numbered points, of Square 25 but projecting to the full series of verticals, 0, 1, 2, etc., of Square 26. The small sinusoid so plotted will have a complete period, and a quarter of a second period, as shown.

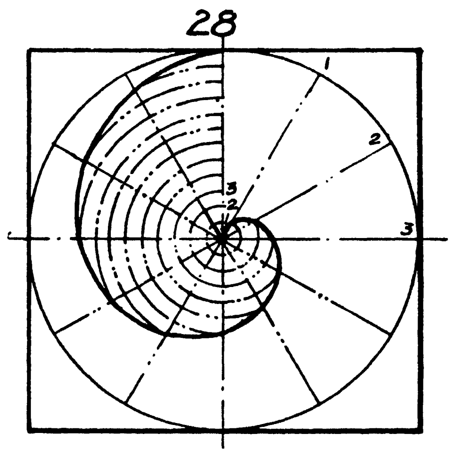
Square 27. Parabola.



This parabola is to have its vertex at S and is to pass through points NW and NE. Only the part within the square is to be drawn.

Divide the west side of the square into equal parts, six (or more), and number them from the top down, point 0 being at NW. Join these points with S. Divide half of the south edge of the square into the same number of equal parts and number them from SW towards S, 0 being at SW. Erect perpendiculars at these points and intersect similarly numbered lines of the two systems. The points so found are the basis for a smooth curve representing the left half of the parabola. The curve fitted at the vertex S must be accurately tangent to the south edge of the square at S. Two parts of the curves should suffice, one part from 0 to point 2, say, and one from 2 to 6. For the right half of the parabola mechanically repeat the point of junction, by symmetry (2′, as marked), and use the same curves again, reversed.

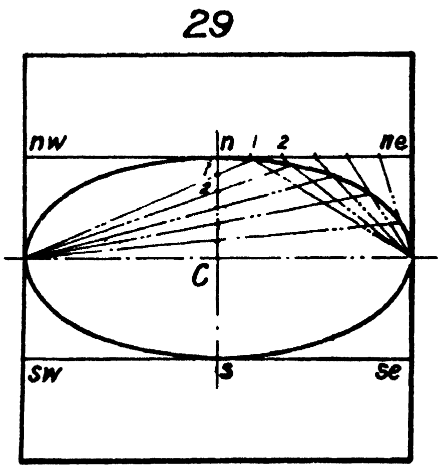
Square 28. Spiral of Archimedes.



In this square inscribe a 3″ circle and divide any radius into 12 equal parts of 1/8″ each. Number them from the center out. Divide the circumference into 12 equal parts by radii at angles of 30°, and number these from *N*, clockwise.

With *C* as center describe arcs of radii, 1/8″, 1/4″, etc., as much of each as may be needed to intersect with the correspondingly numbered radius. Points so determined are points on a spiral of Archimedes, otherwise known as the "equicrescent spiral." Pass a fair curve through the points as shown.

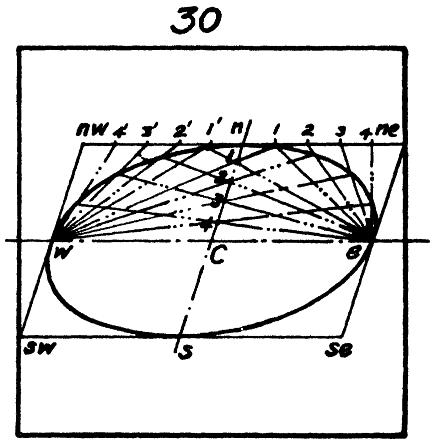
Square 29. Ellipse Inscribed in a Rectangle.



A method of plotting an ellipse, which is of particular value for very large work, is illustrated in this square. The problem is to inscribe an ellipse in a rectangle of $1\frac{1}{2}'' \times 3''$. Find *C*. On the V.C.L. plot *n* and *s* at $\frac{3}{4}''$ from *C*. Call the corners of the rectangle *nw, ne, se* and *sw*. Divide *n-ne* into sixths, numbering the interior division points 1 to 5. Join these to *E*. Divide *nC* into sixths, numbering the interior division points 1 to 5, down.

Draw lines from *W* through these points into the *ne* quadrant and mark where they intersect the correspondingly numbered lines of the other system. The quadrant of the ellipse from *n* to *e* will be defined accurately by the five new points so found. To fit curves follow Art. 132, page 103. The point of juncture may be point 2, 3 or 4. Whichever it is, repeat it mechanically and symmetrically in the other quadrants, by "squaring out" with vertical and horizontal lines, repeating the distances from the center lines by the use of the dividers. Repeat the use of the parts of the curves previously used as described on page 104.

Square 30. Ellipse Inscribed in a Parallelogram.



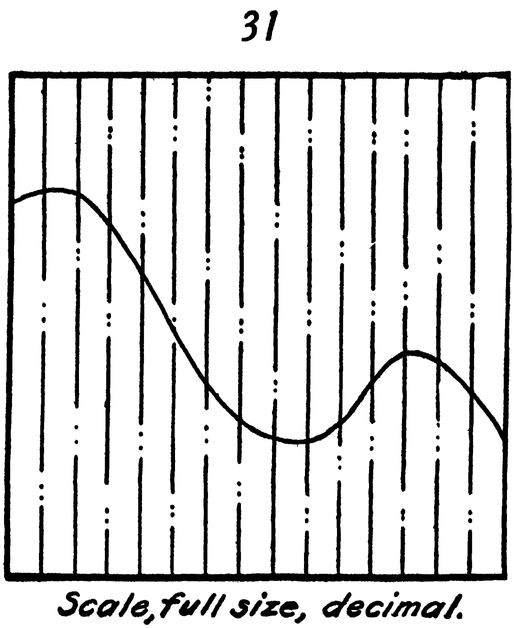
An ellipse may be inscribed in a parallelogram tangent to its sides at their middle points, by extending the method of Square 29.

Draw two horizontal lines above and below the H.C.L. at distances of $2\frac{5}{32}''$. Plot a point, *nw*, on the top line, $\frac{1}{2}''$ from the west edge of the square. Call the right end of the top line *ne*. Mark *sw* and *se* on the bottom line, similarly. Draw *sw-nw, se-ne* and *sCn,* all three parallel. This parallelogram is lettered like the rectangle of Square 29.

Divide *n-ne* into five equal parts of $\frac{1}{4}''$, numbering the interior points from 1 to 4, to the right. Join these points to *e*. Divide *Cn* into five equal parts by spacer, and number the interior points from 1 to 4 down from *n*. Draw lines from *w* through these points into the *ne* quadrant and mark where they intersect the correspondingly numbered lines of the other system. These new points, with *n* and *e*, define a part of the ellipse, tangent to the parallelogram at *n* and at *e*. It can be faired by the curves in two parts. For a second part of the ellipse divide *n-nw* into five parts, number interior points to the left from *n*, and join them to *w*. From *e* draw lines through the numbered points on *nC* into the *nw* quadrant of the parallelogram. Intersecting similarly numbered lines we get six points, in all, to define the *nw* quadrant of the ellipse.

Repeat points of juncture of curves in the lower half ellipse.

Square 31. A Curve Plotted and Faired.



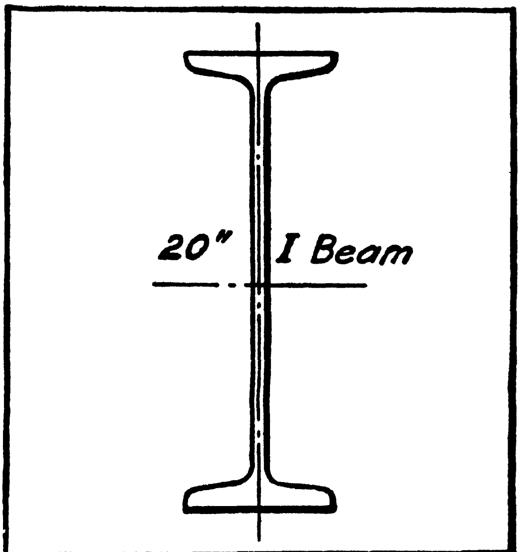
In engineering many important relationships are plotted as curves. Unless there is a reason for a sudden change in properties, such curves are apt to be "smooth curves," i.e., gradually changing curves, not angular. This figure illustrates plotting points with the decimal scale and passing a fair curve through them.

Divide the south edge of the square into intervals of two-tenths of an inch and through the points of division erect vertical construction lines. On these lines, from the base line up, measure off, in order, beginning with the west edge of the square itself, the following distances: 2.″22, 2.″33, 2.″30, 2.″13, 1.″84, 1.″48, 1.″17, 0.″94, 0.″81, 0.″80, 0.″90, 1.″18, 1.″34, 1.″27, 1.″10, and 0.″84.

Finish the pencil work according to Art. 136, p. 106, where this curve is analyzed and sketched.

Square 32. End or Cross-section of an I Beam.

32

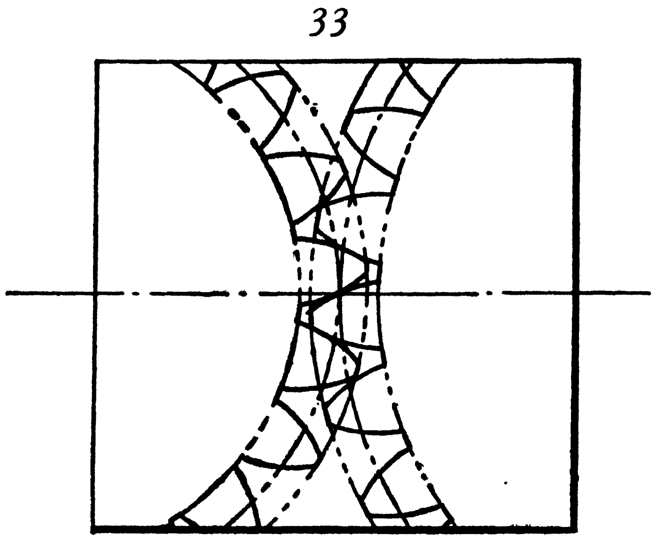


Scale, $1\frac{1}{2}''$ = 1 ft.

This figure represents to a reduced scale the cross-section of a 20″ I beam as rolled from red hot steel in the steel "rolling mill," or "rail mill." The beam is described as having a "web," ¾″ thick, and two "flanges," 7″ wide. The flanges have sharp outer corners but are rounded or filleted at the inner corners, to a ½″ radius, and they join the web with filleted concave corners of ¾″ radius. The drawing is centered at *C*.

Ignore the fillets at first. Draw the flanges as ¾″ thick at the ends. The back surfaces of the flanges have a slope of 1 to 6 (an angle of about 10°). This thickens them where they join the web.

Square 33. Gears in Mesh.



In this square parts of two gear wheels "in mesh" are shown. The centers of the wheels are on the H.C.L., extended to right and left. The pitch circles touch each other at a point called the "pitch point." This point is at *C*, the center of the 3″ square. The radius of the left pitch circle is $2\frac{3}{16}''$. That of the right one is $2\frac{1}{4}''$.

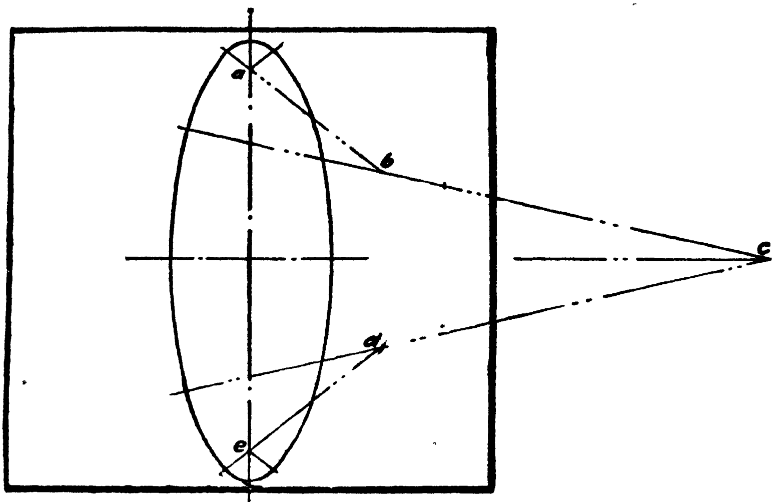
In pencil draw somewhat more than the parts of the pitch circles within the 3″ square.

The pitch distance is 0.″6. Set the bow spacer to half this distance and prick points on both pitch circles, up and down from the pitch point, to beyond the edges of the square.

On the H.C.L., to the right and left of *C*, lay off distances of .3*p* and .4*p*. They are of course 0.″18 and 0.″24 and are found on the decimal scale. Use these points to adjust the compass for the "point circles" and "root circles." Draw in pencil a considerable excess of the root circles. Approximate the involute teeth by circular arcs by the method of pages 158 and 159. In inking only the H.C.L. extends outside the 3″ square, and only small parts of the point and root circles which are parts of the profiles of the teeth should be inked.

Square 34. Three Arc Ellipse.

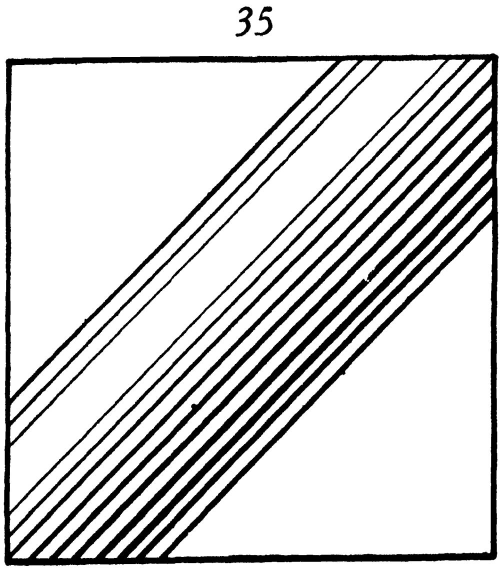
34



Scale, Full Size.

This ellipse, vertically placed, having the major axis on the V.C.L. of the square, measuring $2\frac{7}{8}''$, and its minor axis on the H.C.L., measuring $1''$, is described approximately with circular arcs by a method called the "three arc" or the "eight center" method. The centers are here marked, *a, b, c, d* and *e* and the three radii used are $\frac{3}{16}''$, $1\frac{1}{8}''$, and $3\frac{3}{4}''$. Centers *a, c* and *e* are on the center lines. Centers *b* and *d* are found by the method of Art. 120, p. 93.

Square 35. Line Shading of Inclined Cylinder.



Scale. Full Size.

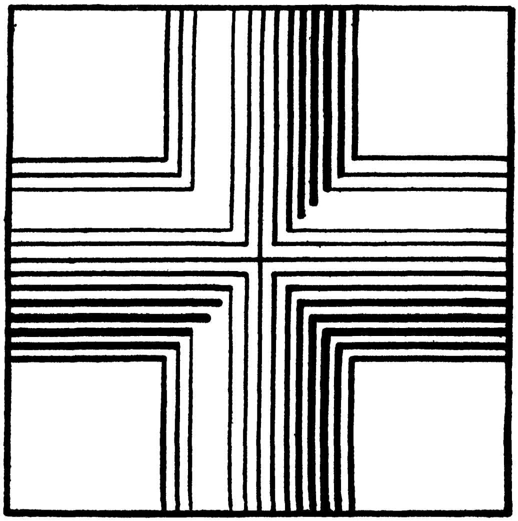
From C lay off on the NW-SE diagonal, both up and down, seven spaces of 3/32″ each. Through the points draw 45° lines parallel to SW-NE, omitting, however, the fourth and fifth lines, counting down from above.

To ink the graded lines which suggest curvature begin at the top with a standard line (0″.015). For the second line screw up the pen's adjusting screw 45°. This line will measure 0″.010. For the third line screw up another 45°, producing a standard fine line, 0″.005 in width. In all cases make the top edge of the ink line agree in position with the pencil line it covers.

After the gap repeat the fine line and then increase each line by 45° increments until you reach 90° beyond shade line width. This will be 0″.035 in width. Repeat this wide line and then decrease by 45° turns of the screw to the edge. This last line will be a standard shade line.

Square 36. Line Shading of Intersecting Cylinders.

36



Scale 2" = 1 ft.

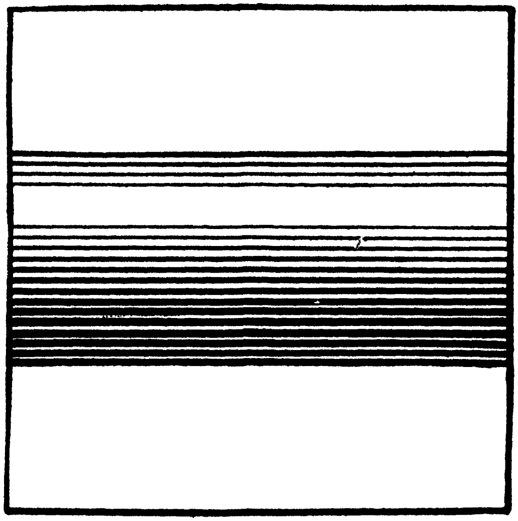
This square represents two intersecting 7″ cylinders to the scale of 2″ = 1 foot. Find *C* and the center lines. Measure 3½″ on each side of each center line and lay off half-inch spaces for the line shading. Draw the horizontal and vertical lines in pencil but omit those that would be the fourth and fifth of each system. These lines all end on the diagonals.

To ink the graded lines which suggest curvature follow the same process as in Square 35 for both the horizontal and the vertical cylinders.

As before, the top (or left) edge will be a standard line, the bottom (or right) edge a shade line and the lines adjacent to the white streak fine lines. The top (or left) edge of each ink line coincides with the pencil line first drawn.

Square 37. Line Shading.

37

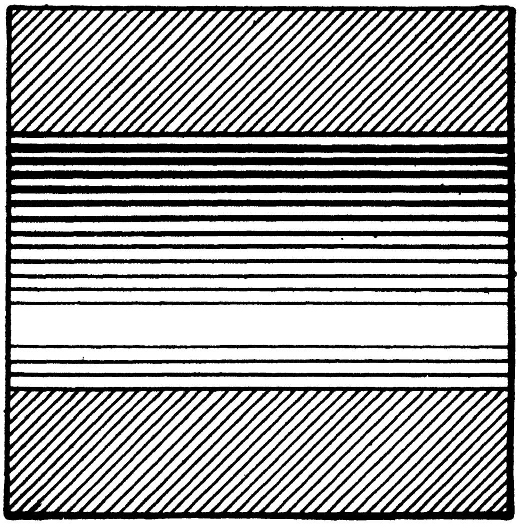


This figure represents a round rod, or cylinder, line shaded in a manner usual on patent office drawings and "display" or advertising drawings. Line shading is a specialty of not much value to the ordinary draftsman. However, it is effective, not hard, and makes one familiar with the capabilities of the right line pen.

Lay the scale along the west edge of the square. Lay off from SW a space of 7/8″, then from that point a space of 13/16″. From that point 1/4″, then a space of 3/16″, and verify that 7/8″ remains to complete the distance to NW. Divide the second and fourth of these spaces, those for 13/16″ and 3/16″ into little spaces of 1/16″. Through all the points draw horizontal lines across the square. *Ink the graded lines beginning at the top with a standard line and thrice reduce the size by screwing up 30° on the adjusting screw. The fourth line will be a fine line. After the gap repeat the fine line and begin increasing by 30° increments, until you reach 90° in excess of the standard shade line. Repeat that thickness and then decrease by 30° decrements to the last line.*

Square 38. Line Shading of Hollow Half-Cylinder.

38



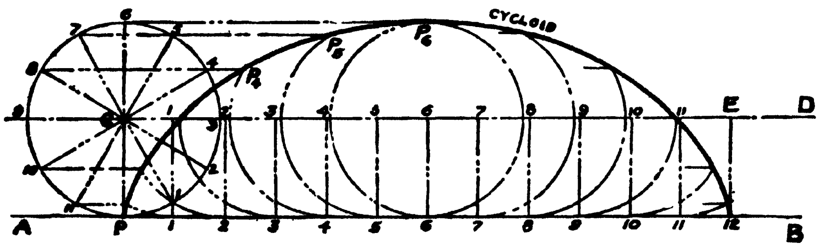
Scale 3" = 1 ft.

This square represents a 12″ block of cast iron with a 6″ bore hole through it, axis horizontal. Imagine the block to be cut in half on a plane through the axis of the bore hole, and the top half to be removed. The exposed bottom half is now on view.

Space the lines for shading 1/12″ apart. The spaces which represent inches on the scale of 1″ = 1 foot, are convenient, but more convenient still are the spaces of the same size on the scale marked 4. In pencil omit the fifth and sixth lines from the bottom.

In inking this hollow cylinder begin with a shade line and increase by 45° openings of the pen's adjusting screw twice. The third line will be 0.″035 in width. Repeat this shade-plus-90° line and then decrease each line by a 45° turn until the line just before the gap is reached. It will be a standard fine line. Repeat the fine line after the gap and increase by 45° until the final line is reached. It will be a standard line.

Rectangle 39. The Cycloid.



This 3″ × 7″ rectangle which may replace any two squares of the standard layout has as its subject the generation of the cycloid. A circle whose center is at *C* in its initial position is supposed to roll along the ground, its center moving to *E*. The point *P*, originally in contact with the ground at *P* describes a cycloid, $P \ldots P_4P_5 \ldots$ in the air until it again touches the ground at point 12 near *B*.

Put *P* ½″ above the south edge of the rectangle and 1″ from the west edge. *C* is 15/16″ above *P*. *CE* is 5⅞″ long. Divide *CE* into 12 equal parts, and number the points of division 1 to 11 as shown. Divide the circumference of the 1⅞″ circle centered at *C*, its initial position, into 12 equal parts by 30° radiating lines. Number them counterclockwise from *P*. Project from these points horizontally to the right and intersect them with the circumferences of the 1⅞″ circles described with centers at the new positions, 1, 2, 3, etc. The figure omits many parts of the construction lines and letters only the three points P_4, P_5 and P_6. It is easy to identify other positions of *P* from these and to put in the smooth curve as shown.

PART II

ENGINEERING DESCRIPTIVE GEOMETRY

A TREATISE ON DESCRIPTIVE GEOMETRY AS THE BASIS OF MECHANICAL DRAWING, EXPLAINING GEOMETRICALLY THE OPERATIONS CUSTOMARY IN THE DRAFTING ROOM

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NEW YORK

JOHN WILEY & SONS, Inc.

LONDON: CHAPMAN & HALL, LIMITED

1941

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PREFACE

The aim of this work is to make Descriptive Geometry an integral part of a course in Mechanical or Engineering Drawing.

The older books on Descriptive Geometry are *geometrical* rather than *descriptive*. Their authors were interested in the subject as a branch of mathematics, not as a branch of drawing.

Technical schools should aim to produce engineers rather than mathematicians, and the subject is here presented with the idea that it may fit naturally in a general course in Mechanical Drawing. It should follow that portion of Mechanical Drawing called *Line Drawing,* the aim of which is to teach the handling of the drawing instruments, and should precede courses specializing in the various branches of drawing, such as Mechanical, Structural, Architectural, and Topographical Drawing, or the "laying off" of ship lines.

The various branches of drawing used in the different industries may be regarded as dialects of a common language. A drawing is but a written page conveying by the use of lines a mass of information about the geometrical shapes of objects impossible to describe in words without tedium and ambiguity. In a broad sense all these branches come under the general term Descriptive Geometry. It is more usual, however, to speak of them as branches of Engineering Drawing, and that term may well be used as the broad label.

The term Descriptive Geometry will be restricted, therefore, to the common geometrical basis or ground work on which the various industrial branches rest. This ground work of mathematical laws is unchanging and permanent.

Each branch of Engineering Drawing has its own abbreviations and special methods which it adapts to its own particular field, and these conventional methods change from time to time, keeping pace with changing industrial methods.

Descriptive Geometry, though unchanged in its principles, has recently undergone a complete change in point of view. In changing its purpose from a *mathematical* one to a *descriptive* one,

or from being a training for the geometrical powers of a mathematician to being a foundation on which to build up a knowledge of some branch of engineering, the methods of drawing in use in drafting rooms must be followed, and they must be systematized and explained.

The following points distinguish this work from others on the same subject:

1. Coordinates are used to fix the positions of points by their distances from the planes of projection. This serves to make all problems exact in position as well as exact in shape. Usually there is but one correct solution to a problem and the student is forced to realize that the subject is an exact mathematical science.

2. Three planes of projection are used for all objects except simple surfaces of revolution. This accords with drawing room practice.

3. The auxiliary plane of projection at an angle is made the standard method of finding the true shapes of inclined faces. The revolving of an object into parallelism with a plane of projection is a secondary method, as it is in drafting rooms.

4. The steps necessary to lay out planes, prisms, pyramids and curved surfaces are made definite and direct.

5. Methods of working out the intersections of planes and curved surfaces are systematized and numbered. If a solution for a given problem by a system of cutting planes is not at once evident to the student he can test each one of the list until a proper one is found.

6. Problems of infinite lines and planes are postponed until the student has had a complete drill on finite and tangible objects. This order of progress makes a hard subject easy.

7. One chapter shows how to pass from the formal, exact, coordinate method to the freedom of the drafting room, where axes are omitted but the geometrical laws based on them are adhered to except when short cuts are purposely made.

8. A final chapter gives directions for drawing sheets which put in practice all the principles taught. A selection of a part of them, or similar subjects, will provide the necessary drawing board course to fix the subject in the student's mind.

T. W. J.

June, 1941

CONTENTS

PART II.

CHAPTER I.

NATURE OF ORTHOGRAPHIC PROJECTION.
THE FINITE STRAIGHT LINE.

1. Orthographic Projection.—The object of Mechanical Drawing is to represent solids with such mathematical accuracy and precision that from the drawing alone the object can be built or constructed without deviating in the slightest from the intended shape. As a consequence the "working drawing" is the ideal sought for, and any attempt at artistic or striking effects as in "show drawings" must be regarded purely as a side issue of minor importance. Indeed mechanical drawing does not even aim to give a picture of the object as it appears in nature, but the views are drawn for the mind, not the eye.

The shapes used in machinery are bounded by surfaces of mathematical regularity, such as planes, cylinders, cones, and surfaces of revolution. They are not random surfaces like the surface of a lump of putty or other surfaces called "shapeless." These definite shapes must be represented on the flat surface of the paper in an unmistakable manner.

The method chosen is that known as "*orthographic projection.*" If a plane is imagined to be situated in front of an object, and from any salient point, an edge or corner, a perpendicular line, called a "projector," is drawn to the plane, this line is said to project the given point upon the plane, and the foot of this perpendicular line is called the projection of the given point. If all salient points are projected by this method, the *orthographic drawing* of the object is formed.

2. Perspective Drawing.—The views we are accustomed to in artistic and photographic representations are "Perspective Views." They seek to represent objects exactly as they appear in nature. In their case a plane is supposed to be erected between the human eye and the object, and the image is formed on the plane by supposing straight lines drawn from the eye to all salient points of

the object. Where these lines from the eye, or "Visual Rays," as they are called, pierce the plane, the image is formed.

Fig. 1 represents the two contrasted methods applied to a simple object, and the customary nomenclature.

An orthographic view is sometimes called an "Infinite Perspective View," as it is the view which could only be seen by an eye at an infinite distance from the object. "The Projectors" may then be considered as parallel visual rays which meet at infinity, where the eye of the observer is imagined to be.

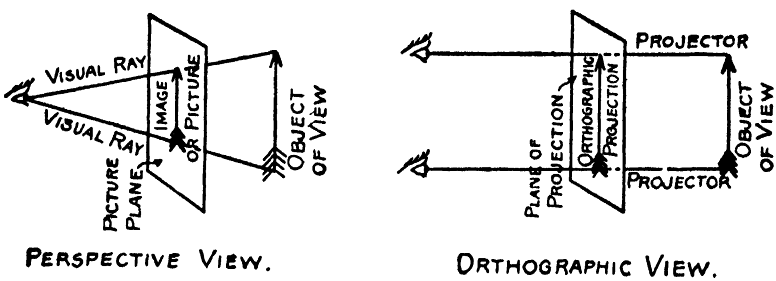


FIG. 1.

3. The Regular Orthographic Views.—Since solids have three "dimensions," length, breadth and thickness, and the plane of the paper on which the drawing is made has but two, a single orthographic view can express two only of the three dimensions of the object, but must always leave one indefinite. Points and lines at different distances from the eye are drawn as if lying in the same plane. From one view only the mind can imagine them at different distances by a kind of guess-work. If two views are made from different positions, each view may supplement the other in the features in which it is lacking, and so render the representation entirely exact. Theoretically two views are always required to represent a solid accurately.

To make a drawing all the more clear, other views are generally advisable, and three views may be taken as the average requirement for single pieces of machinery. Six regular views are possible, however, and an endless number of auxiliary views and "sections" in addition. For the present, we shall consider only the "regular views," which are six in number.

4. Planes of Projection.—A *solid object* to be represented is supposed to be surrounded by planes at short distances from it, the planes being perpendicular to each other. From each point of every salient edge of the object, lines are supposed to be drawn perpendicular to each of the surrounding planes, and the succession of points where these imaginary projecting lines cut the planes are supposed to form the lines of the drawings on these planes. One of the planes is chosen for the plane of the paper of the actual drawing. To bring the others into coincidence with it, so as to have all of them on one flat sheet, they are imagined to be unfolded from about the object by revolving them about their lines of intersection with each other. These lines of intersection, called "axes of projection," separate the flat drawing into different views or elevations.

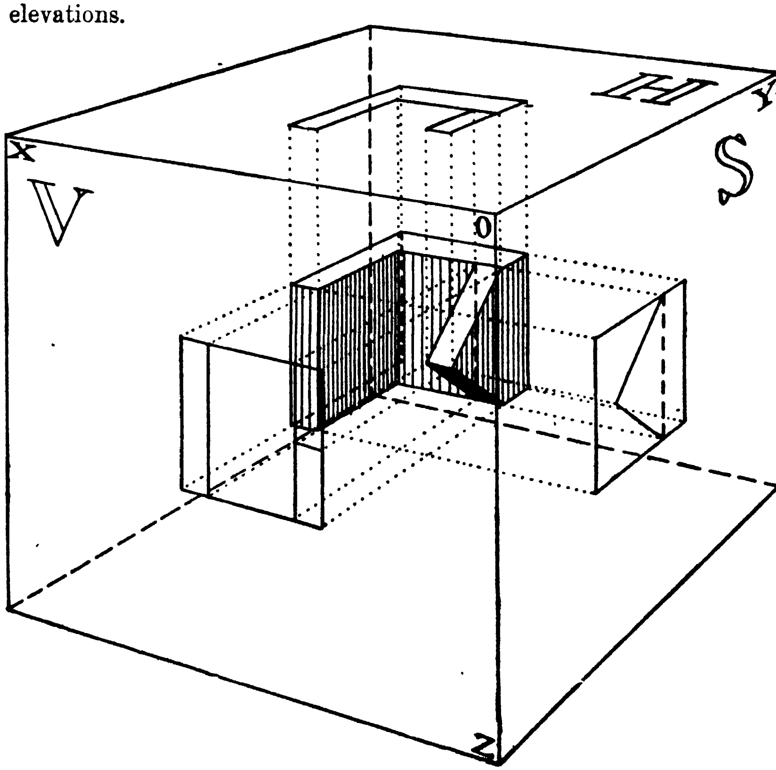


FIG. 2.

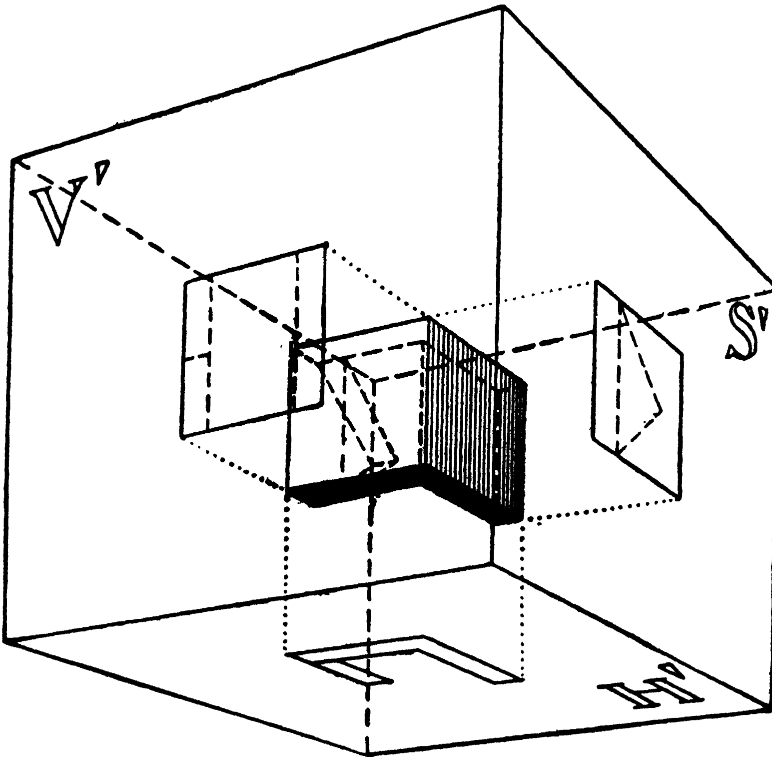


FIG. 2a.

Fig. 2 is a true perspective drawing of a solid object and the planes as they are supposed to surround it. This figure is not a mechanical drawing, but represents the mental process by which the mechanical drawing is supposed to be formed by the projection of the views on the planes. In this case the planes are supposed to be in the form of a perfect cube. The top face of the cube shows the drawing on that face projected from the solid by fine dotted lines. Remember that these fine dotted lines are supposed to be perpendicular to the top plane. This drawing on the top plane is called the "plan." On the front of the cube the "front view" or "front elevation" is drawn, and on the right side of the cube is

the "right side elevation." Three other views are supposed to be drawn on the other faces of the cube, but they are shown on Fig. 2a, which is the perspective view of the cube from the opposite point of view, that is, from the back and from below instead of from in front and from above.

This method of putting the object to be drawn in the center of a cube of transparent planes of projection is a device for the imagination only. It explains the nature of the "projections," or "views," which are used in engineering drawing.

5. Development or Flattening Out of the Planes of Projection.— Now imagine the six sides of the cube to be flattened out into one plane forming a grouping of six squares as in Fig. 3. What we

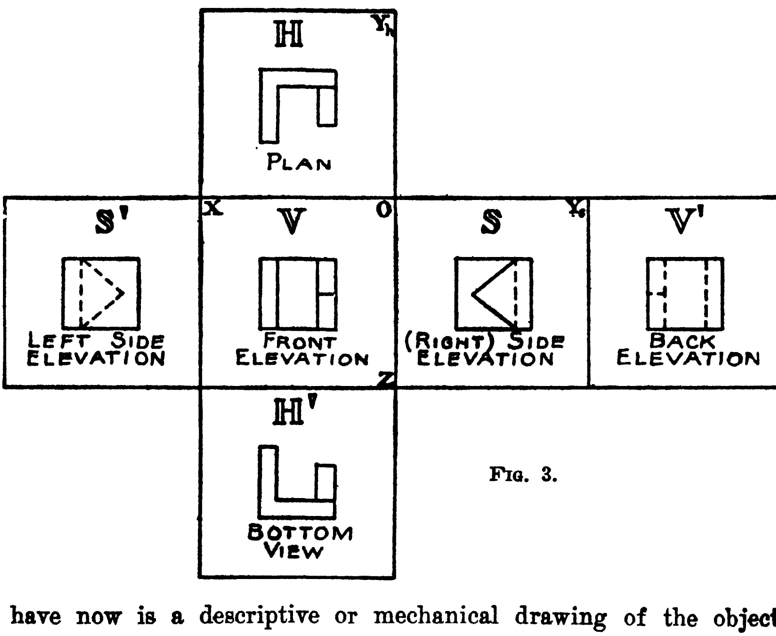


FIG. 3.

have now is a descriptive or mechanical drawing of the object showing six "views." The object itself is now dispensed with and its projections are used to represent it. These six views are what we call the "regular views." With one slight change they correspond to the regular set of drawings of a house which architects make.

The set of six "regular" projections would not be altered by passing the transparent planes at unequal distances from each other, so long as they surround the object and are mutually perpendicular. They may form a rectangular parallelopiped instead of a cube without altering the nature of the views.

It will be noticed also that views on opposite faces of the cube differ but little. Corresponding lines in the interior may in one case be full lines and in the other "broken lines." Broken lines (formed by dashes about $\frac{1}{8}''$ long, with spaces of $\frac{1}{16}''$) represent parts concealed by nearer portions of the object itself. All edges project upon the plane faces of the cube, forming lines on the draw-

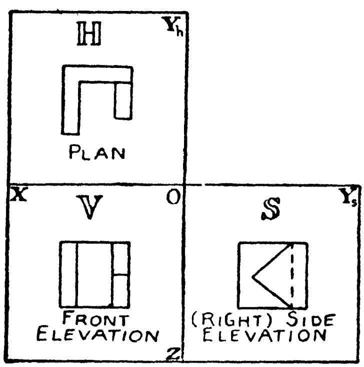


FIG. 4.

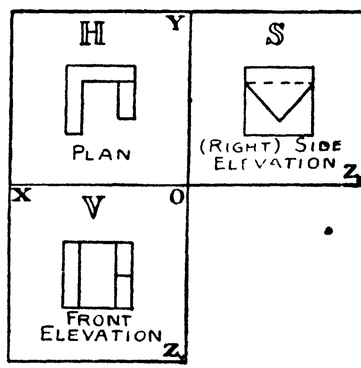


FIG. 5.

ings, the edges concealed by nearer portions of the object forming broken lines.

6. The Reference Planes and Principal Views.—In drawings of parts of machinery six regular views are usually unnecessary. The three views shown in Fig. 2 are the "Principal Views," and others are needed only occasionally. The planes of those views are the "Reference Planes."

These views, when flattened from their supposed position about the object into one plane, give the grouping in Fig. 4.

Another arrangement of the same views, obtained by unfolding the planes of the cube in a different order, is shown in Fig. 5. These two arrangements are standard in mechanical drawing, and are those most used.

7. The Nomenclature.—The nomenclature adopted is as follows: The "Reference Planes," or three principal planes of projection, are called from their position, the Horizontal Plane, or H, the Vertical Plane, or V, and the (right) Side Plane, or S. The plane S is by some called the "Profile Plane." The point O (Fig. 2), in which they meet, is the "Origin" of coordinates. The line OX, in which H and V intersect, is called the "Axis of X," or "Ground Line." The line OY, in which H and S meet, is called the "Axis of Y," and the line OZ, in which V and S meet, is called the "Axis of Z." The three axes together are called the "Axes of Projection."

Since drawings are considered as held vertically before the face, it is considered that the plane V coincides at all times with the "Plane of the Paper." In unfolding the planes from their positions in Fig. 2 to that in Fig. 4, it is considered that the plane H has been revolved about the axis of X (line OX), through an angle of 90°, until it stands vertically above V. In the same way S is considered to be revolved about the line OZ, or axis of Z, until it takes its place to the right of V.

The arrangement in Fig. 5 corresponds to a different manner of revolving the plane S. It is revolved about the axis of Y (OY) until it coincides with the plane H, and is then revolved with H, about the axis of X, until both together come into the plane of the paper, or V.

The three other faces of the original cube of planes of projection are appropriately called H′, V′, and S′. On account of the similarity of the views on them, to those on H, V and S, they are but little used. S′ alone is fairly common since a grouping of planes H, V and S′ is at times more convenient than the standard group H, V and S.

8. Meaning of "Descriptive Geometry."—The aim of Engineering or Mechanical Drawing is to represent the shapes of solid objects which form parts of structures or machines. It shows rather the shapes of the *surfaces* of the objects, surfaces which are usually composed of plane, cylindrical, conical, and other surfaces. In the drawing room, by the application of mathematical laws and principles, views are constructed. These are usually Plan, Front

Elevation, and Side Elevation, and are exactly such views as would be obtained if the object itself were put within a cage of transparent planes, and the true projections formed.

It is these mathematical laws or rules which form the subject known as Descriptive Geometry. A drawing made in such a way as to bring out clearly these fundamental laws of projection, by the use of axes of projection, etc., may be conveniently called a "Descriptive Drawing."

In the practical application of drawing to industrial needs, short-cuts, abbreviations, and special devices are much used (their nature depending on the special branch of industry for which the drawing is made). In addition, the axes of projection are usually omitted or left to the imagination, no particular effort being made to show the exact mathematical basis provided the drawing itself is correct. Such a drawing is a typical "Mechanical Drawing." By the addition of axes of projection and similar devices, it may be converted into a strict "Descriptive Drawing."

9. The Descriptive Drawing of a Point in Space.—The imaginary process of making a descriptive drawing consists in putting the object within a cube of transparent planes, and projecting points and lines to these planes. In practice the projections are formed all on a single sheet of paper, which is kept in a perfectly flat shape, by the application of rules of a geometrical kind derived from the imaginary process. The key to the practical process is in these rules. The first subject of exact investigation should be the manner of representing a point in space by its projections and the fixing of its position as regards the "reference planes" by the use of coordinate distances.

Figs. 6 and 7 show the imaginary and the practical processes of representing P by its projections.

Fig. 6 is a perspective drawing showing the cube of planes, or rather the three sides of the cube regularly used for reference planes. The cube must be of such size that the point P falls well within it. The perpendicular projectors of P are PP_h, PP_v and PP_s. The origin and the axes of projection are all marked as on Fig. 2.

In Fig. 7 the "field" of the drawing, that part of the paper devoted to it, is prepared by drawing two straight lines at right angles to represent the axes of projection, lettering the horizontal line XOY_s and the vertical one ZOY_h. This field corresponds to that of Fig. 4, the outer edges of the squares being eliminated since there is no need to confine each plane to the size of any particular cube. If more field is needed, the lines are simply extended. It must be remembered that these axes are quite different from the coordinate axes used in plane analytical geometry, or graphic algebra. These divide the field of the drawing into four

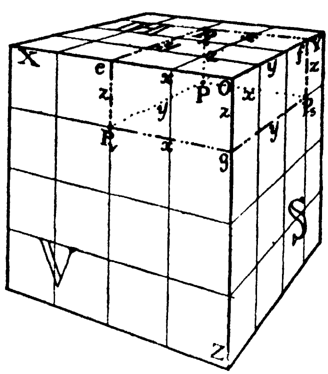


FIG. 6.

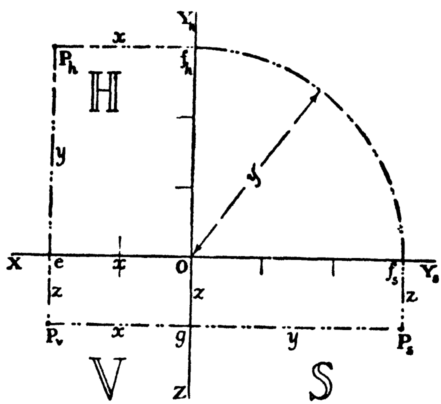


FIG. 7.

quadrants, of which three represent *three different planes,* mutually perpendicular, the fourth being useful only for the purposes of construction.

Usually the upper left quadrant, the "North-West," represents H; the lower left quadrant, or "South-West," represents V, and the lower right quadrant, or "South-East," represents S.

Occasionally the upper right quadrant represents S as in Fig. 5, page 212. The horizontal axis is then lettered XOZ_s and the vertical one, reading up, Z_vOY.

10. Coordinates of a Point in Space.—A *point in space* is located by its perpendicular distances from the three planes of projection, that is to say, by the length of its projectors. These

distances are called the coordinates of the point, and are designated by x, y and z. In the example given, these values are 2, 3 and 1. In Fig. 6 PP_s, the 𝕊 projector of P, is two units long, or $x=2$. The perpendicular distance to the plane 𝕍, the 𝕍 projector, PP_v, is three units long. $y=3$. In the same way PP_h, the ℍ projector, is one unit long. $z=1$.

In describing the point P, it is sufficient to state that it is the point for which $x=2$, $y=3$, and $z=1$. This is abbreviated conveniently by calling it the point P $(2, 3, 1)$, the coordinates, given in the bracket, being taken always in the order x, y, z.

The projectors, the true coordinate distances, are shown in Fig. 6 by lines of *dots*, not dashes.

If in each plane ℍ, 𝕍 and 𝕊, perpendicular lines are drawn (dashes, not dots) from the projections of P to the axes, we shall have the lines P_he and P_hf, P_ve and P_vg, P_sg and P_sf. These lines meet in pairs at e, g, and f, forming a complete rectangular parallelopiped of which P and O are the extremities of a diagonal. The other corners of the parallelopiped are P_h, P_v, P_s, e, f and g.

Each coordinate, x, y and z, appears in *four* places along four edges of the parallelopiped, as is marked in Fig. 6.

The distances x, y and z are all considered positive in the case shown.

In Fig. 7, the descriptive drawing of the point P, P itself does not appear, being represented by its projections, P_h, P_v and P_s. The true projectors (shown in Fig. 6 by lines of *dots*) do not appear, but in place of each coordinate *three* distances equal to it do appear, so that in Fig. 7 x, y and z each appear in three places as is there marked. Thus x appears as P_hf_h, eO, and P_vg. As all these are measured to the left from the vertical axis, ZOY_h, it follows that P_hep_v is a straight line, or P_h is vertically above P_v. It is often said that P_v "projects vertically" to P_h. In the same way P_v "projects horizontally" to P_s. The distance y appears as eP_h, Of_h, Of_s, and gP_s. The point f appears double as f_h and f_s.

Usual Order of Plotting Projections of a Point.—Lay off x to left of origin, y above and z below it, thus locating points e, f_h and g, Fig. 7. Draw quadrant f_hf_s, center at O, or 45° line OL, Fig. 8, p. 218. Then "square out" to locate P_h, P_v and P_s.

11. Three Laws of Projection for $\mathbb{H}$, $\mathbb{V}$ and $\mathbb{S}$.—The three relations shown by Fig. 7 amount to three laws governing the projections of a point in the three views, and must always be rigidly observed. They may seem easy and obvious when applied to one point, but when dealing with a multitude of points it is not easy to observe them unfailingly.

They may be thus tabulated:

(1) P_h must be vertically above P_v.

(2) P_s must be on the same horizontal line as P_v.

(3) P_s must be as far to the right of OZ as P_h is above OX.

From these laws it follows that if two projections of a point are given, the third is easily found. In Fig. 7, if two of the corners of the figure $P_hf_hf_sP_sP_v$ are given, the figure can be graphically completed. Much of the work of actual mechanical drawing consists in correctly locating two of the projections of a point by plotting or measuring, and of finding the other projection by the application of these laws or of this construction. Constant checking of the points between the various views of a drawing is a vital principle in drawing.

On the drawing board the horizontal projection of P_v to P_s is naturally done by the T-square alone, and the vertical projection of P_h to P_v by T-square and triangle. There are two methods of carrying out the third law in addition to the graphical construction of Fig. 7. Fig. 8 shows a graphical method which makes use of a 45° line, OL, in the construction space, instead of the quadrant of a circle. It is easier to execute, but the meaning is not so clearly shown. The third method is by the use of the dividers directly to transfer the y coordinate from whichever place it is first plotted, to the other view in which it appears.

12. Paper Box Diagrams.—When studying a descriptive drawing, such as Fig. 8, imagine as you look at P_v that the real point P lies *back of the paper,* at a distance equal to eP_h.

Whenever figures in the text following seem hard to grasp, carry out the following scheme. Trace the figure on thin paper, or on tracing cloth. Using Fig. 8 as an example, and supposing it to have been traced on semitransparent paper, hold the paper before you and fold the top half back 90° on the line XOY_s. Then, view-

ing P_h from above, imagine the true point P to lie below the paper at a distance equal to eP_v, in the same way as you imagine P to lie back of P_v at a distance equal to eP_h.

After flattening the paper, fold the right half back 90° on the line ZOY_h, and, viewing P_s from the right, imagine P to lie back of P_s a distance P_vg. Finally, crease the paper on the line OL, OL itself forming a groove, not a ridge, and bend the paper on all

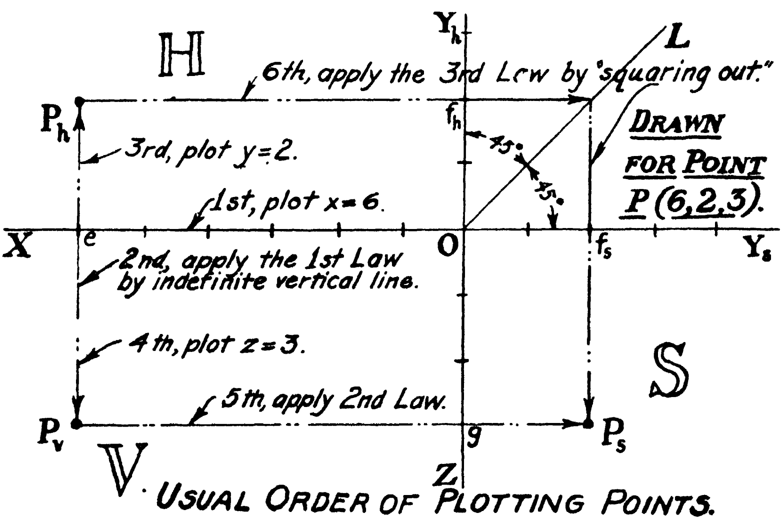


FIG. 8.

the creases at once, so that H and S fold back into positions at right angles to V and to each other at the same time.

The "construction space" Y_hOY_s is thus folded away inside and OY_h and OY_s come in contact with each other. Fig. 9 shows the final folding partly completed.

No diagram, however complicated, can remain obscure if studied from all sides in this manner.

To have a convenient name, these space diagrams may be called "Paper Box Diagrams."

Figs. 4 and 5 make good paper box diagrams, while Fig. 3 may be traced and folded into a perfect cube which, if held in proper position, will give the exact views shown in Figs. 2 and 2a, omitting the solid object supposed to be seen in the center of those figures.

13. Wire-mesh Cages.—These are cubical cages similar to Fig. 10, formed of wire-mesh screens, representing the planes $\mathbb{H}$, $\mathbb{V}$, $\mathbb{S}$ and $\mathbb{S}'$. On these screens chalk marks may be made and the planes, being hinged together, may afterward be brought into coincidence with $\mathbb{V}$, as represented in Fig. 10a.

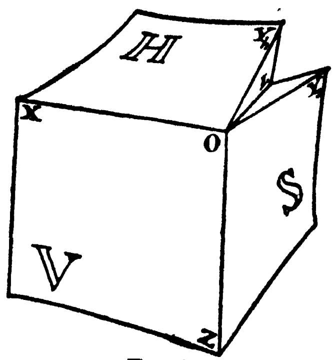


FIG. 9.

In order to plot points in space within the cage, pieces of wire about 20 inches long, with heads formed in the shape of small loops or eyes, are used as *point markers.* They may be set in holes drilled in the base of the cage at even spaces of 1″ in each direction, so that a marker may be set to represent any point whose x or y coordinates are even inches. To adjust the marker to a required z coordinate, it may be pulled down so that the wire projects through the base, lowering the head the required amount.

In Fig. 10 a point marker is set to the point P (11, 4, 6), and the lines on the screens have been put on with chalk, to represent all the lines analogous to those of Fig. 6.

Fig. 10a represents the descriptive drawing produced by the development of the screens in Fig. 10. It is analogous to Fig. 7.

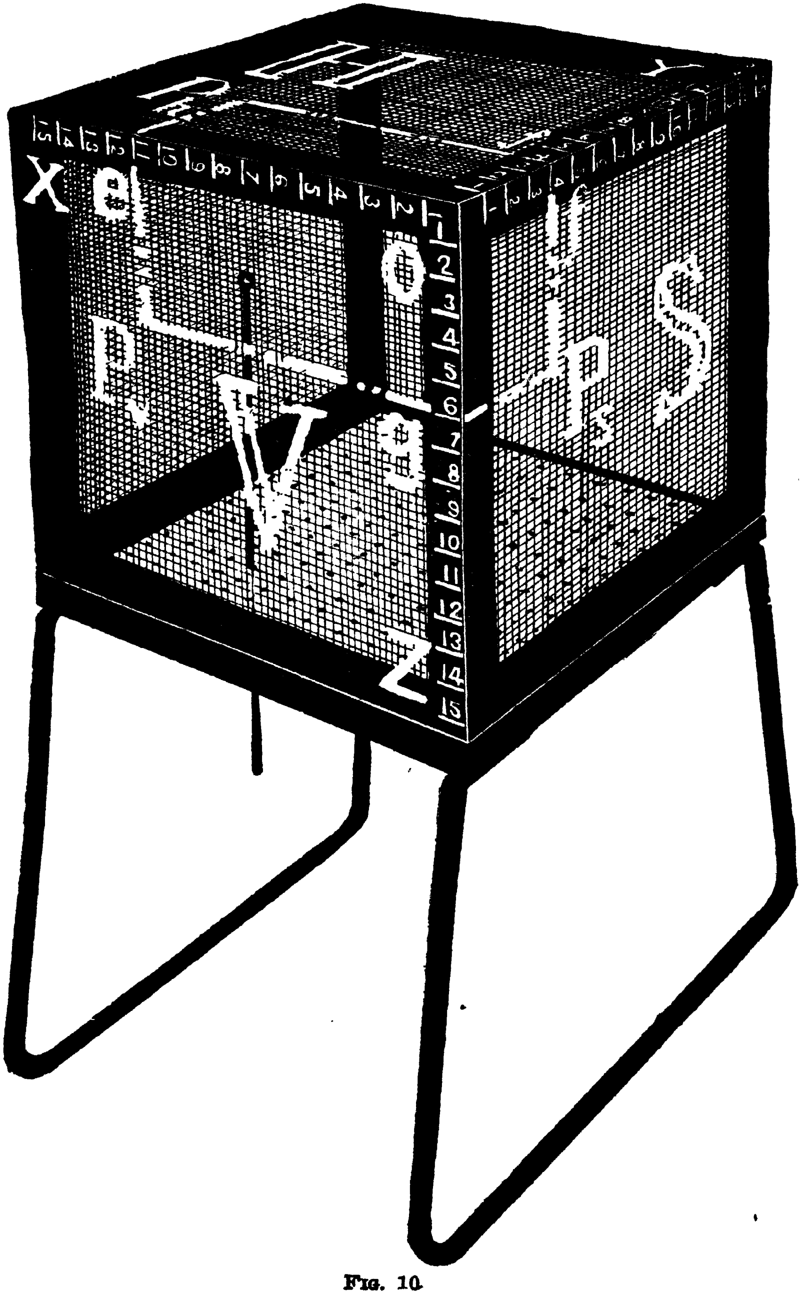


Fig. 10

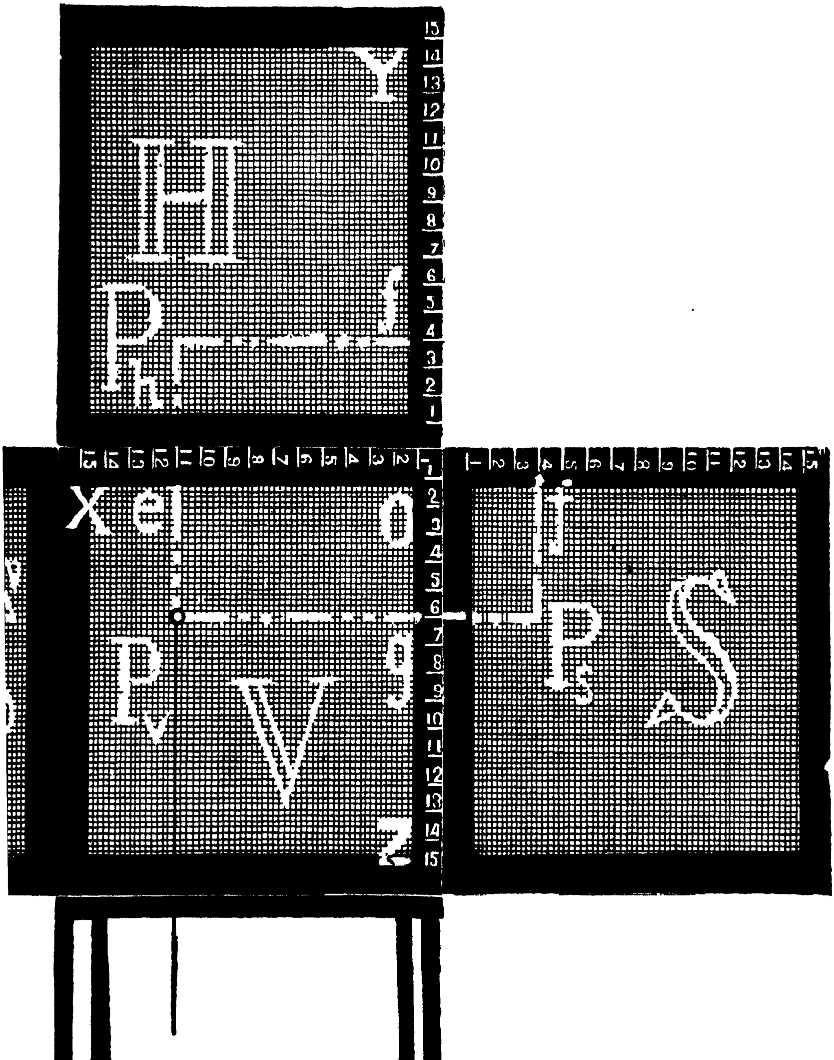


FIG. 10a.

These wire-mesh cages are not essential for a clear understanding of the course. Cross-section paper should be used in the solution of the problems and folded to make "space" or "paper box" diagrams, to illustrate knotty points. These folded diagrams are practically miniature cages. The full-size cages are very convenient for class-room demonstrations.

Several points may be thus marked in space and cord may be threaded through the loops, so that any plane figure may be shown in space, and its corresponding orthographic projections may be drawn on the planes in chalk.

This Chapter has so far treated the *Nature of Orthographic Projection* in general and the projection of a point in particular. The rest of the chapter is devoted to the *Projection of the Finite Straight Line.*

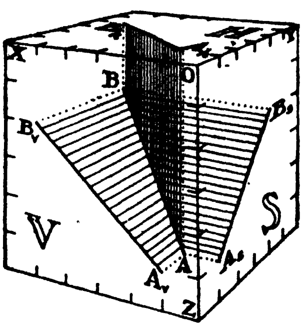


FIG. 11.

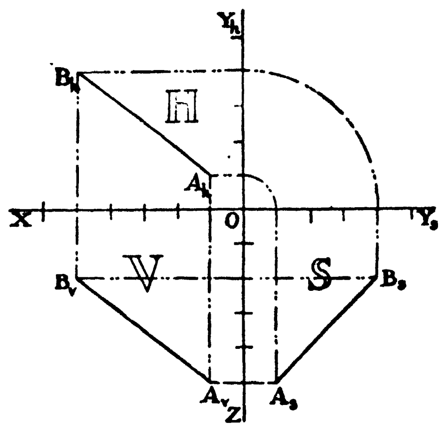


FIG. 12.

14. The Finite Straight Line in Space: One not Parallel to any Reference Plane, or an " Oblique Line."—A line of any kind consists merely of a succession of points. Its orthographic projection is the line formed by the projections of these points.

In the case of a straight line, the orthographic projection is itself a straight line, though in some cases this straight line may degenerate to a single point, as mathematicians express it.

To find the H, V and S projections of a finite straight line in space, the natural course is to project the extremities of the line on each reference plane and to connect the projections of the extremities by straight lines. We shall not consider this as requiring proof here.

The projectors from the different points of a straight line form a plane perpendicular to the plane of projection. This "projector-plane," of course, contains the given line. If the straight line is a limited or finite line the projector-plane is in the form of a quadrilateral having two right angles. Thus in Fig. 11 the **H** projectors of the straight line AB form the figure AA_hB_hB, having right angles at A_h and B_h. These projector-planes AA_hB_hB, AA_sB_sB, and AA_vB_vB are shown clearly in this perspective drawing, in which they are shaded.

Fig. 12 is the descriptive drawing of the same line AB which has been selected as a "line in space," that is, as one which does not obey any special condition. In such general cases the projections are all shorter than the line itself. As drawn, the extremities are A (1, 1, 5) and B (5, 4, 2).

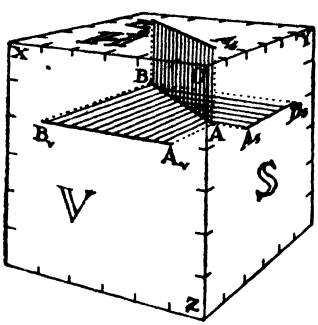


FIG. 13.

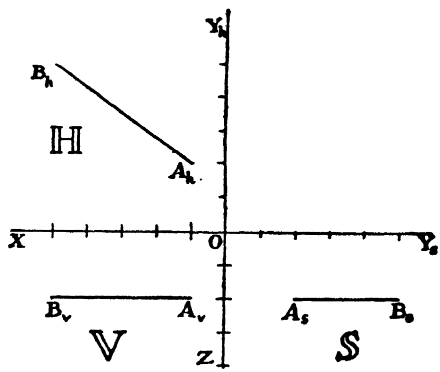


FIG. 14.

15. Line Parallel to One Reference Plane, or Inclined Line.— A line which is parallel to one reference plane, but is not parallel to an axis, appears projected at its true length on that reference plane only.

Figs. 13 and 14 show a line five units long, connecting the points A (1, 2, 2) and B (5, 5, 2). A_hB_h is also five units in length but A_vB_v is but four and A_sB_s is three. The projector-plane AA_hB_hB is a rectangle.

The student should construct on coordinate paper the two similar cases. For example: the line C (4, 2, 1), D (1, 2, 5) is parallel to **V**; E (2, 1, 2), F (2, 5, 5) is parallel to **S**.

16. Line Parallel to One of the Axes and thus Parallel to Two Reference Planes.—If a finite straight line is parallel to one of the axes of projection, its projection on the two reference planes which intersect at that axis, will be equal in length to the line itself. Its projection on the other reference plane will be a single point.

Fig. 15 is the perspective drawing and Fig. 16 the descriptive drawing, of a line parallel to the axis of X, four units in length. Its extremities are the points A $(1, 2, 2)$ and B $(5, 2, 2)$. In $\mathbb{H}$

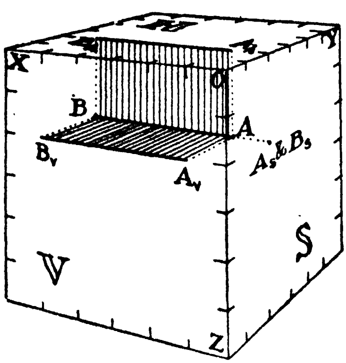


FIG. 15.

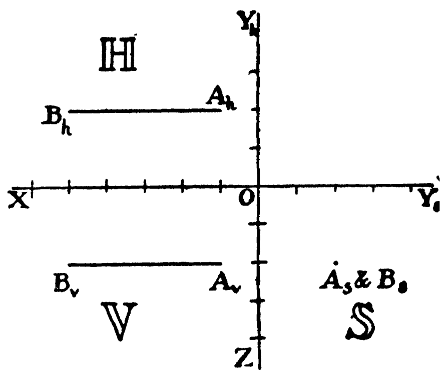


FIG. 16.

and $\mathbb{V}$ its projections are four units long. The projector-planes AA_hB_hB and AA_vB_vB are rectangles. The $\mathbb{S}$ projector-plane degenerates to a single line BAA_s. It will be seen that the coordinates of the extreme points of the line differ only in the value of the x coordinate. In fact, any point on the line will have the y and z coordinates unchanged. It is the line (x variable, 2, 2).

The student should construct for himself descriptive drawings of lines parallel to the axis of Y and the axis of Z, using preferably "coordinate paper" for ease of execution. Good examples are the lines C $(1, 1, 1)$, D $(1, 5, 1)$ and E $(3, 1, 1)$, F $(3, 1, 4)$. Points on the line CD differ only as regards the y coordinate. It is a line parallel to the axis of Y. EF is parallel to the axis of Z and z alone varies for different points along the line.

17. Foreshortening.—The projection of a line oblique to the plane of projection is shorter than the original line. This is called foreshortening. The H, V and S projections of Fig. 12, and the V and S projections of Fig. 14, are foreshortened. It is a loose method of expression, but a common one, to say that a line is foreshortened when it is meant that a certain projection of a line is shorter than the line itself. When subscripts are omitted and A_hB_h is called AB, it is natural to speak of the line AB as "foreshortened" in the plan view or projection on H. This inexact method of expression is so customary that it can hardly be avoided, but with this explanation no misconception should be possible.

18. Inclined and Oblique Lines.—The words Inclined and Oblique are taken generally to mean the same thing, but in this subject it becomes necessary to draw a distinction, in order to be able to specify without chance of misunderstanding the exact nature of a given line or plane. A line will be described as:

Parallel to an axis, when parallel to any axis. As a special case a line parallel to the axis of Z may be called simply *vertical.* A line parallel to the axis of X or Y is often called *horizontal.*

Inclined, when parallel to a reference plane, but not parallel to an axis. When parallel to H it may be be called an *inclined horizontal* line. The line AB, Fig. 13, is an illustration.

Oblique, when not parallel to any reference plane or axis. The typical "line in space" is oblique. AB, of Fig. 11, is one.

19. Inclined and Oblique Planes.—A plane will be called:

Horizontal, when parallel to H. The V projector-plane in Fig. 15 is of this kind.

Vertical, when parallel to V or S. The H projector-plane in Fig. 15 is of this kind.

Inclined, when perpendicular to one reference plane only. When perpendicular to H, it may be called an *inclined-vertical* plane. The H projector-plane of Fig. 13 is of this kind.

Oblique, when not perpendicular to any reference plane. Planes of this kind will appear later on.

The surface of the solid of Fig. 2 is composed of vertical, horizontal, and inclined planes (but no oblique plane). Its edges are

lines, parallel to the axes of X, Y and Z; and inclined lines (because parallel to $\mathbb{S}$); but no oblique lines.

20. The Point on a Given Line.—It is self-evident that if a given point is on a given line, *all* the projections of the point must lie on the projections of the line.

If the middle point of a line AB is projected, as C in Fig. 17, C_h, C_v, and C_s, the projections of the middle point, bisect the projections of the line.

This principle of proportionality applies to other points than the bisector. If any point divides AB into unequal parts, the projec-

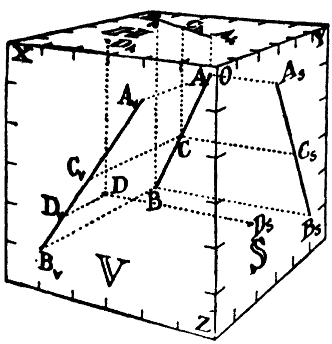


FIG. 17.

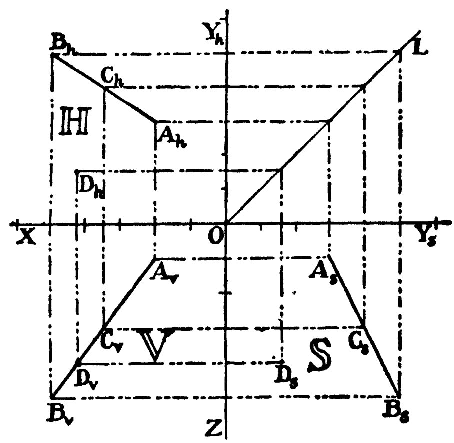


FIG. 18.

tions of the point will divide the projectors of AB in parts having the same ratio. A point one-tenth of the distance from A to B will, by its projections, mark off one-tenth of the distance on A_hB_h, A_vB_v, etc.

The points illustrated in Figs. 17 and 18 are A (2, 3, 1), B (5, 5, 5) and C ($3\frac{1}{2}$, 4, 3). It will be noticed that the x coordinate of C is the mean of those of A and B, and the y and z coordinates of C also are the mean of the y and z coordinates of A and B.

Unless all three of the projections of a point fall on the projections of a line, the point is not in the given line. If one of the projections of the point be on the corresponding projection of the line, one other projection of both point and line should be ex-

amined. If in this second projection it is found that the point does not lie on the line, it shows that the point in space lies in one of the projector-planes.

Thus the point D in Fig. 18 has its $\mathbb{V}$ projection on A_vB_v, but its $\mathbb{H}$ and $\mathbb{S}$ projections are not on A_hB_h and A_sB_s. D is not a point in the line AB but is on the $\mathbb{V}$ projector-plane of AB, as is clearly shown on Fig. 17.

In the case illustrated, D_v bisects B_vC_v. The plotting of the $\mathbb{V}$ projection of a point is governed only by its x and z coordinates. D_v bisects B_vC_v because its x and z coordinates are the means of the x and z coordinates of B and C. The y coordinate of D, however, has no connection with the y coordinates of B and C.

21. Zero Coordinates.—Points having zero coordinates are sometimes perplexing. If one coordinate is zero, the point in question is on one of the reference planes, and indeed coincides with one of its own projections. Since x is the length of the orthographic projector of the point P upon the plane $\mathbb{S}$, if $x=0$, this projector disappears and the point P and its $\mathbb{S}$ projection P_s coincide. If the point Q (0, 3, 1) is to be plotted it will be found to coincide with P_s in Fig. 6. The descriptive drawing will correspond with Fig. 7 with all lines to the left of ZOY_h omitted.

Any point whose y coordinate is zero lies upon the plane $\mathbb{V}$. The point R (6, 0, 3), plotted after the method of Fig. 8, would be where P_v is, with R_h at e and R_s at g.

A Point with Two Zero Coordinates Is on an Axis.—T (0, 2, 0), for example, plots like Fig. 8, with all points removed, except f_h and f_s, which are the point T itself, as well as T_h and T_s.

Problems I.

Before proceeding to Chapter II the student must assure his mastery of Chapter I by solving a fair number of the following problems. In Isherwood Hall wire-mesh cages are available, and black-boards ruled in 2″ squares. Midshipmen have also "log pads" whose sheets are ruled front and back. The fronts are ruled in rectangles for tabulating logarithms. The backs are decimally ruled and lend themselves admirably to problems given in units as these are. Paper, specially ruled for problems, is often issued.

Midshipmen are particularly urged to use forty minutes of the evening study period, preceding every drawing recitation, for

study of the text, and for solution of problems. **By Working Problems Seek to Acquire Facility in the Following Tasks:**

a. To plot *points* rapidly and accurately after the model of Fig. 8.

b. After joining *two plotted points,* to recognize whether the line so given is "vertical," "horizontal" (i.e., "horizontal and parallel to *X*," "horizontal and parallel to *Y*," or "inclined horizontal,") "inclined" or "oblique."

c. After plotting *three points* and joining each to each, in each view, to pronounce whether the plane of the triangle is "horizontal," "vertical and parallel to *V*," or "vertical and parallel to S" (in these cases two views are lines only) "inclined" or "inclined-vertical" (in these cases one view is a line only), or "oblique" (no view shuts up to a line).

d. After plotting *four points* and joining each to each, to determine whether the figure represents a quadrilateral with its diagonals or a "tetrahedron." (Watch the three points of crossing in the centers of the views. If they obey the laws of projection, they represent the intersection of two diagonals. If they do not the figure is a solid, not a plane).

e. After plotting a tetrahedron or irregular triangular pyramid, to select which of the interior crossing lines of any one view is a full line, which a broken line. (The full one is the edge of the solid which is nearest to the plane of projection at that moment considered, but to determine what line is nearest to V, for example, one must examine H or S where the y coordinates appear.)

(1 to 4 for solution with wire-mesh cage.)

1. Plot by the use of the wire markers the three points, *A, B* and *C,* whose coordinates are (5, 12, 11), (3, 3, 3), and (12, 4, 8), and draw the projections on the screens in chalk. By joining point to point a triangle and its projections are formed. Use string for joining the points, and chalk lines for joining the projections.

2. Form the triangle as above with the following coordinates:
(11, 3, 2), (12, 6, 12) and (14, 12, 7).

3. Form the triangle as above with the following coordinates:
(7, 0, 11), (9, 9, 0) and (2, 2, 3).

4. Form the triangle as above with the following coordinates:
(0, 11, 13), (14, 3, 3) and (14, 13, 0).

5. Make the descriptive drawing of a triangle in three views by plotting the vertices and joining them by straight lines. The vertices are the points *A* (1, 10, 8), *B* (5, 6, 8), *C* (9, 2, 4).

6. Make the descriptive drawing as above, using the points
A (12, 2, 5), *B* (0, 8, 6), *C* (4, 6, 0).

7. Make the descriptive drawing as above, using the points
A (3, 4, 2), *B* (13, 8, 10), *C* (5, 10, 14).

8. The four points A (3, 3, 3), B (3, 3, 15), C (15, 3, 15), and D (15, 3, 3) form a square. Make the descriptive drawing. Why are two projections straight lines only? What are the coordinates of the center of the square?

9. The four points A (12, 2, 12), B (2, 2, 12), C (7, 14, 12), and D (7, 6, 2) are the corners of a solid tetrahedron. Make the descriptive drawing, being careful to mark concealed edges.

10. Make the descriptive drawing of the tetrahedron A (2, 3, 2), B (9, 8, 3), C (4, 8, 9), D (12, 3, 6), marking concealed edges by broken lines.

11. Make the descriptive drawing of the tetrahedron A (3, 2, 4), B (6, 8, 2), C (8, 1, 8), D (2, 7, 8).

12. Plot the points A (12, 7, 7), B (8, 13, 5), C (2, 9, 2), and D (6, 3, 4). Why is the $\mathbb{V}$ projection a straight line?

13. Make the descriptive drawing of the tetrahedron A (13, 5, 3). B (1, 5, 3), C (7, 2, 6), D (7, 8, 6). To which axis is the line AB parallel? To which axis is CD parallel?

14. Plot and join the points A (11, 3, 3), B (3, 3, 3), C (7, 9, 7), and D (15, 9, 7). Do AC and BD meet at a point?

15. A line connects the points A (5, 2, 6) and B (5, 12, 6). What are the coordinates of the point C, the center of the line? What are the coordinates of D, a point on the line, one-tenth of the way from A to B?

16. Same with points A (6, 6, 2) and B (6, 6, 12).

17. Draw the line AB, whose extremities are A (2, 7, 4) and B (14, 2, 4). On what view does its true length appear? What is this length? What are the coordinates of a point C on the line one-third of its length from A? Give the true shape of the $\mathbb{H}$ projector-plane, stating length of each edge and what angles are right angles. Same for $\mathbb{V}$ projector-plane.

18. Draw the line A (4, 2, 2), B (4, 11, 8). On what view does its true shape appear, and what is its length? Give the true shape of its $\mathbb{H}$ projector-plane, stating length of each edge. Same for $\mathbb{V}$ projector-plane.

19. Draw the line A (0, 4, 8), B (9, 4, 1). On what view does its true shape appear? What are the coordinates of a point C on AB one-third of its length from A?

20. The $\mathbb{H}$ projection of C (8, 2, 6) lies on the $\mathbb{H}$ projection of the line A (10, 1, 9), B (2, 5, 2). Is the point on the line?

21. Same as Problem 20, with line A (2, 1, 8), B (8, 10, 5), and point C (4, 4, 7).

22. A triangle is formed by joining the points A (6, 3, 1), B (10, 3, 10) and C (2, 3, 10). In what view or views does the true length of AB appear? In what view or views does the true length of BC appear? Mark the center of the triangle (one-third

the distance from the center of the base BC to the vertex A) and give its coordinates?

23. Same with points A (5, 9, 6), B (5, 3, 1) and C (5, 3, 11).

24. Same with points A (10, 1, 4), B (7, 10, 4) and C (1, 4, 4).

25. The $\mathbb{V}$ projections of the points A (8, 1, 2), B (10, 3, 8), C (4, 3, 10) and D (2, 1, 4) form a square. Draw the projections and connect them point to point. What are the coordinates of the center where AC and BD intersect?

26. Plot the parallelogram A (11, 3, 3), B (3, 3, 3), C (7, 9, 7), D (15, 9, 7). Draw the diagonals (dash-dot-dot lines) and give the coordinates of their intersection E. We know $ABCD$ to be a quadrilateral in a plane perpendicular to $\mathbb{S}$, because the view on $\mathbb{S}$ is a straight line. Also the projections of E obey the three laws of projection. Is the plane inclined or oblique?

27. Plot A, B and C of Problem 26, but not D. In its place plot F (15, 5, 7). This is a change in the y-coordinate alone. Draw the "outlines" in all three views very distinctly. Draw the interior crossing lines very faintly at first. Is $ABCF$ a plane figure? AC and BF seem to intersect on both $\mathbb{H}$ and $\mathbb{V}$. Do these seeming intersections obey the first law on p. 217? Is the second law obeyed? Since they do not, $ABCF$ is a tetrahedron. Consider the crossing lines on $\mathbb{V}$. Which is nearest to $\mathbb{V}$, AC or BF? Look to $\mathbb{H}$ or to $\mathbb{S}$ to decide this. The nearest to $\mathbb{V}$ is drawn as a full line on $\mathbb{V}$, the other as a broken line. Consider $\mathbb{H}$ next. Is BF or AC the nearest to $\mathbb{H}$? $\mathbb{V}$ gives doubtful information. Decide from $\mathbb{S}$. In considering $\mathbb{S}$ imagine the plane of projection to be folded into cubical form so that OY_s represents the whole $\mathbb{H}$ plane as seen from $\mathbb{S}$.

28. Plot the quadrilateral A (11, 10, 3), B (5, 10, 9), C (7, 2, 7), D (11, 4, 3). The diagonals (dash-dot-dot lines) intersect at E. Give E's coordinates. Is the plane of $ABCD$ inclined or oblique?

29. Plot A, B and C of Problem 28, but in place of D plot F (11, 4, 11). $ABCF$ is a tetrahedron. Connect each point to each in all three views, drawing outlines distinctly, interior lines faintly, until decision is made as to concealed edges.

On $\mathbb{V}$ CF is an interior line. Is it nearer to $\mathbb{V}$ than other parts of the solid? Decide by consulting $\mathbb{H}$ or $\mathbb{S}$ and redraw CF distinctly, full or broken, according to your decision.

On $\mathbb{H}$ AC and FB are interior lines. The figure on $\mathbb{H}$ is the view of the solid represented on $\mathbb{V}$ when looked at from directly above, *i.e.*, from the part of the paper where $\mathbb{H}$ is drawn. Is A_vC_v nearer to the axis, OX, than F_vB_v, or the reverse? Redraw the lines according to your decision.

On $\mathbb{S}$ CB and FA are interior lines. Which is the nearest to $\mathbb{S}$? Decide from $\mathbb{V}$, according to which is there nearest to OZ, or from $\mathbb{H}$, according to which is there nearest to OY_h.

CHAPTER II.

THE TRUE LENGTH OF A LINE IN SPACE.

22. The Use of an Auxiliary Plane of Projection.—To find the true length of a "line in space," or oblique straight line, an auxiliary plane of projection is of great value, and is constantly used in all branches of Engineering Drawing.

The theory of the auxiliary plane of projection, to which the letter U is applied, is shown by a series of figures, from Fig. 19 to Fig. 22-A. They explain the relation of the plane U to H, V and S, the projection of the line upon U, and the unfolding of the planes. The final theoretical result, Fig. 22-A, is shown again in Fig. 22-B, with the planes extending indefinitely away from the origin. It is the way actual work is executed in the drawing room. The theoretical series, leading to it, explains the mental process and justifies the actual performance.

We call it finding the *true length of a line*. Such is its simplest application. In practice it is applied to many lines at once, namely, to *plane figures*, as will be seen later.

23. Traces of the Auxiliary Plane U.—In Fig. 19 the oblique line AB is shown surrounded by the regular planes of projection. The end points are projected by lines of dots to H, V and S. The projections, A_hB_h, A_vB_v, and A_sB_s, are supposedly shorter than AB, and would be so if the figure were not a perspective drawing. To show AB at its true length a new plane of projection is chosen. This plane is located by its "traces." The traces are the intersections of the plane with H, V and S. Planes H and V are shown extended considerably to the left.

The "U-plane" to be chosen must be parallel to AB and to *one of the projections of* AB. Let us choose A_hB_h. U is to be parallel to the whole projector-plane, AA_hB_hB. Let us choose some definite point on the axes of X and mark the letter X there.

From X draw a line on $\mathbb{H}$, parallel to A_hB_h. This line is marked XM. From X draw a line on $\mathbb{V}$, parallel to OZ, giving us XN. These are the traces of the $\mathbb{U}$-plane. XM is called the "inclined trace" and XN the "vertical trace." In the most general case, there can be, of course, three traces, but one only is inclined. The others are always horizontal or vertical.

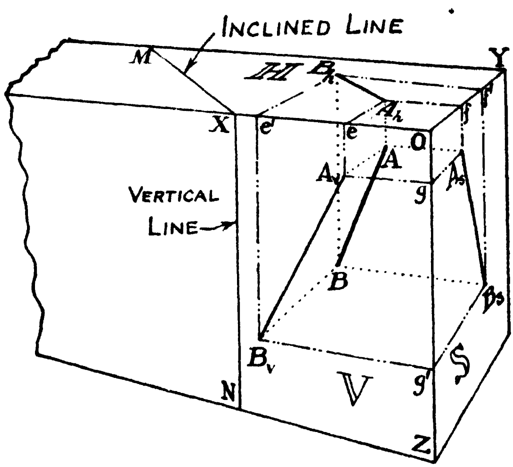


FIG. 19.

24. The $\mathbb{U}$-Projectors.—Let us now consider the parts of $\mathbb{H}$ and $\mathbb{V}$, to the left of the traces, to be removed. It is much as if the figure represented the end of a timber and a carpenter, wishing to cut the end at a slant, had drawn a slant line XM, and a square line XN, as guides to follow in sawing off the end. The part to be cut off is represented by Fig. 20, and the newly cut surface is the new auxiliary plane of projection, $\mathbb{U}$.

Imagine now the line AB to be projected upon $\mathbb{U}$, Fig. 20, by perpendicular projectors, the extremities being AA_u and BB_u. A_uB_u is the new projection, or view, on $\mathbb{U}$. The projector plane AA_uB_uB is a rectangle and A_uB_u is therefore equal in length to AB.

Imagine A_u to be connected to A_h and A_v by lines representing the shortest distances on the surfaces of Fig. 20. We get A_ukA_h

and $A_u l A_v$. Both $A_u k$ and $k A_h$ are lines perpendicular to XM. $A_u l$ and $l A_v$ are both perpendicular to XN. Similarly $B_u k'$ and $k' B_h$ are perpendicular to XM, and $B_u l'$ and $l' B_v$ are perpendicular to XN.

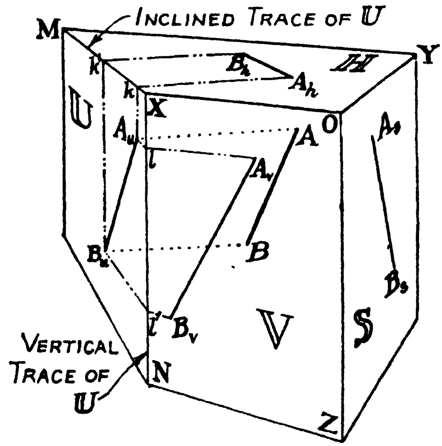


FIG. 20.

Tight elastic cords connecting A_u to A_h and A_v would take these positions, spontaneously.

25. Development of the Auxiliary Plane U.—Let us now forget

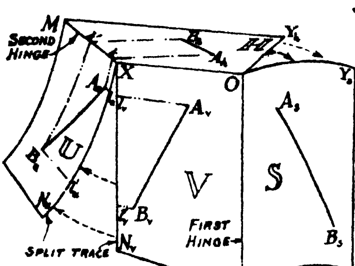


FIG. 21-A.

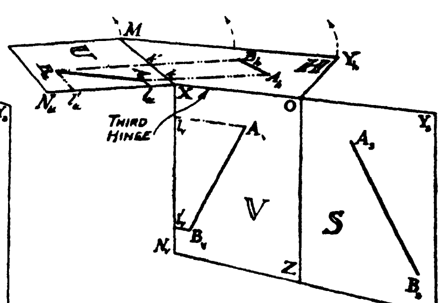


FIG. 21-B.

the actual points A and B, in the interior, and confine attention only to the surfaces H, V, S and U of Fig. 20. We are now to split the edges XN and OY, to peel off the surfaces and develop them

on the plane of $\mathbb{V}$. Using OZ as the first hinge swing $\mathbb{S}$ into coincidence with $\mathbb{V}$, as shown in Fig. 21-A. Using XM as the second hinge, swing $\mathbb{U}$ up into coincidence with $\mathbb{H}$. We now have the stage shown in Fig. 21-B. Finally take OX as the third hinge, and swing $\mathbb{H}$ and $\mathbb{U}$ together, up from that position, to the position shown in Fig. 22-A, a perspective of the surfaces when perfectly flattened out or developed. Fig. 22-B shows the development held squarely before the face, and freed of outside boundaries to the planes. In practice, of course, Fig. 22-B is constructed directly without previous diagrams except in the mind's eye.

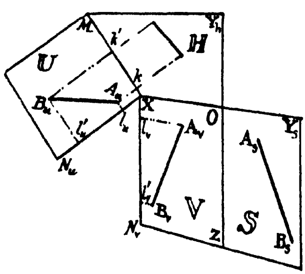


FIG. 22-A.

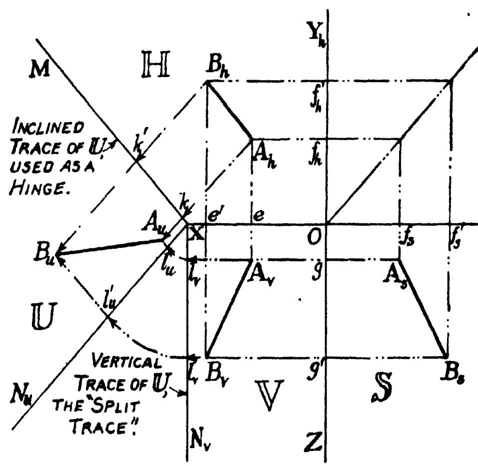


FIG. 22-B.

26. The Fourth Law of Projection, for Constructing the Auxiliary View on the Plane, $\mathbb{U}$.—Let us look only to Fig. 22-B and imagine that we have, given, the $\mathbb{H}$, $\mathbb{V}$ and $\mathbb{S}$ views of the line AB. We are required to construct an auxiliary view to obtain the true shape. A point X is first chosen, well to the left (but not beyond A_hk, a line drawn perpendicular to A_hB_h). XM is drawn parallel to A_hB_h, XN_v parallel to OZ and XN_u perpendicular to XM. These are the developed traces of $\mathbb{U}$, constructed to accord with the theory as has been explained.

From A_h and B_h draw A_hk and B_hk', perpendicular to XM, and

extend them indefinitely beyond XM. From k and k' lay off the z-coordinates of A and B, as lifted by the dividers from the V or the S view. Thus $kA_u = eA_v = f_sA_s$; $k'B_u = e'B_v = f'_sB_s$. Join A_uB_u. It is the true length of AB.

This projection of A_h upon the inclined trace by a perpendicular line, extended beyond the trace, and the laying off, beyond the trace, of the coordinate missing on the H view, amounts to a *fourth law of projection*. In our example the inclined trace was taken on H, but in practice it is taken on V or S quite as often.

If we call that plane to which the U-plane is hinged (the inclined trace of U acting as the hinge) the "adjacent plane," a general statement of the fourth law is as follows:

4. (a) The line connecting P_u to $P_{\text{adjacent view}}$ is a line perpendicular to the inclined trace of U.

(b) P_u is at a distance from the inclined trace of U equal to that coordinate of P which is missing on the adjacent view.

These rules should be memorized. The part b is spoken of as the "rule of the missing coordinate" and its application prevents confusion and error. Use it to check the graphical work when constructing the auxiliary view.

Each regular plane of projection shows two coordinates of any given point. H shows x and y. V shows x and z. S shows y and z. The U-plane shows one only. Note the location of the inclined trace. If it crosses H, U has the z coordinate since H does not have z. If it crosses V, U has y. If it crosses S, U has x.

27. The Graphical Application of the "Missing Coordinate."— The final operation in the application of the 4th law of projection, that of measuring off the missing coordinate, may be done by scale, by dividers, or by a geometrical construction as shown in Fig. 22-B by arrows proceeding from A_v to A_u, and from B_v to B_u. The projection from A_h to A_u and from B_h to B_u was across the "inclined trace" of U. The projection from A_v to l_v is perpendicular to the other trace of U, a trace which we may well call the "split" trace of U, since it must be split to permit development. The graphical application of the missing coordinate consists in project-

ing from a regular projection of a point, as from A_v, perpendicularly to a split trace, as $A_v l_v$. With the junction of the traces as center, in this case, the point X, the distance Xl_v is used as radius and l_v carried by the arc of a circle to l_u, on the other line representing, the split trace. This arc is then continued by a tangent, $l_u A_u$, perpendicular to XN_u, until it intersects the line of projection across the inclined trace, in this case $A_h k A_u$, at A_u.

28. The True Length of a Line.—The full procedure for finding the true length of an oblique line is as follows: (1) Pass an auxiliary plane of projection parallel to the given line and to one of its projections. To do this, draw an inclined trace of $\mathbb{U}$, parallel to one of the projections of the given line. At the point where the inclined trace cuts an axis of coordinates, draw lines perpendicular to the axis and to the inclined trace. These lines are two positions of a split trace of $\mathbb{U}$. (2) Apply the fourth law of projection to the ends of the given line by projecting perpendicularly across the inclined trace, as far as may be needed, and by laying off (by scale, by dividers or by graphical construction), the missing coordinate, from the inclined trace into the field of $\mathbb{U}$. (3) Join the ends of the line thus plotted on $\mathbb{U}$.

29. Alternative Method of Developing the Auxiliary Plane, $\mathbb{U}$.—A method of developing the plane $\mathbb{U}$, by splitting the inclined trace and using the vertical or horizontal trace as hinge, is sometimes used. Of course it results in exactly the same view on $\mathbb{U}$ but located at a different place on the paper. It is rare and can be passed aside here.

30. Alternating Positions of the Plane, $\mathbb{U}$.—In our choice of a point, X, on Fig. 19, we had considerable latitude. Practical considerations are called on and the aim is so to choose X that the view on $\mathbb{U}$ is near to the regular views, but may not overlap or confuse in any manner.

So long as we are dealing with a single line there are three major choices possible. We described passing a $\mathbb{U}$-plane parallel to AB and to $A_h B_h$. We might have passed one parallel to AB and to $A_v B_v$, in which case we would have had the inclined trace on $\mathbb{V}$ and the split trace, or traces, on $\mathbb{H}$ and $\mathbb{S}$, in the form of horizontal lines. Very often only one split trace is needed.

Had we chosen to pass a plane parallel to AB and A_sB_s the inclined trace would have been on $\mathbb{S}$ and split traces on $\mathbb{H}$ and $\mathbb{V}$.

To study such combinations a student is advised to plot on coordinate paper points A (12, 12, 4), B (20, 20, 16) and X (20, 0, 0). Complete the construction and fold the figure into a paper box diagram, the space between the two lines for the split trace being creased from X, down the middle, and folded back, just as the space between OY_h and OY_s of Fig. 8 is folded back in Fig. 9.

The variations in position of $\mathbb{U}$ may be studied by holding the paper box in such positions as to interchange planes $\mathbb{H}$, $\mathbb{V}$ and $\mathbb{S}$.

The student must be able at will to pass a $\mathbb{U}$-plane perpendicular to $\mathbb{H}$, to $\mathbb{V}$ or to $\mathbb{S}$. In treating practical problems conditions limit our freedom and we must be ready for all cases.

31. The Method Applied to a Plane Figure.—The special value of this use of the auxiliary plane is seen when one operation serves to give the true length of a number of lines at once, and thus shows a whole plane figure in its true shape.

In Fig. 23 the polygon $ABCDE$ is shown by its projections, the point A alone being lettered. It is noticeable that in $\mathbb{V}$ the edges all form one straight line. The $\mathbb{V}$ projector-planes of the various edges are therefore all parts of the same plane, and the polygon itself is a plane figure placed perpendicular to $\mathbb{V}$. It may be said the polygon is " seen on edge " in $\mathbb{V}$.

An auxiliary plane $\mathbb{U}$ has been taken parallel to the plane of the polygon, and therefore perpendicular to $\mathbb{V}$. The trace XM being parallel to the $\mathbb{V}$ projections of the edges, this auxiliary plane serves to show the true length of all the edges at once. The projection on $\mathbb{U}$ is the true shape of the polygon $ABCDE$. In the case illustrated, the $\mathbb{U}$ projection discloses the polygon to be a regular pentagon with sides all equal and angles equal. Sides are foreshortened and angles distorted on the regular projections.

To use this method of finding the true shape of a plane surface:
(1) *Find* a view in which the surface in question is seen on edge.*
(2) *Pass a $\mathbb{U}$-plane parallel to it.*

* If a surface is oblique there is no view "on edge," and a double process must be used. See Art. 113, p. 340. Need for such work is very rare.

This figure is well adapted to tracing and folding into a paper box diagram.

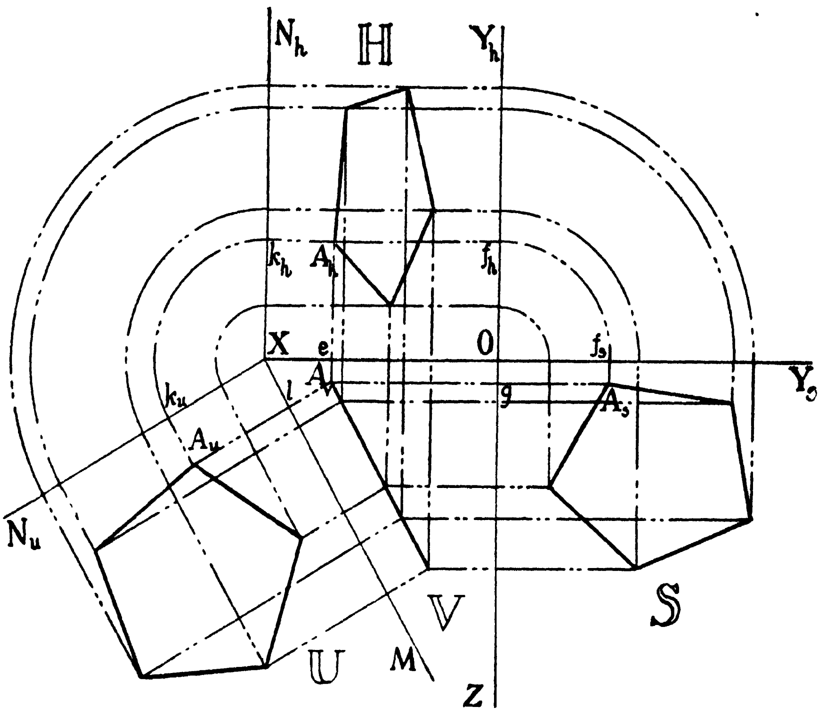


FIG. 23.

32. The True Length of a Line by Revolving About a Projector. —A second method of finding the true length of a line seems in a way simpler, but proves to be of much less value in practical work. The method consists in supposing an oblique line AB to be revolved about a projector of some point in the line until it becomes parallel to one of the planes of reference. In this new position it is projected to the reference plane as of its true length.

In Fig. 24 the V projector-plane of the line AB has been shaded for emphasis (A is the point $(1, 1, 5)$, and B is the point $(5, 4, 2)$). The projector AA_v has been selected at will, and the V projector-plane (of which the line AB is one edge) has been rotated about

AA_v as an axis until it has come into the position $A_vB'_vB'A$. In its new position, AB' projects to ℍ as $A_hB'_h$. This is the true length of the line. During its rotation the point B has moved to B', but in so doing it has not revolved about A as its center, but about the point b on A_vA extended. bA_v is equal in length to BB_v. B_v moves to B'_v, revolving about A_v as a center. In Fig. 25, the corresponding descriptive drawing, the original projections are

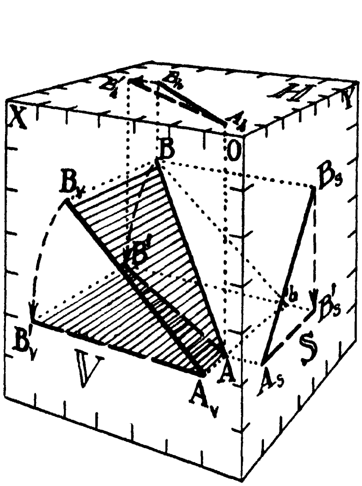


FIG. 24.

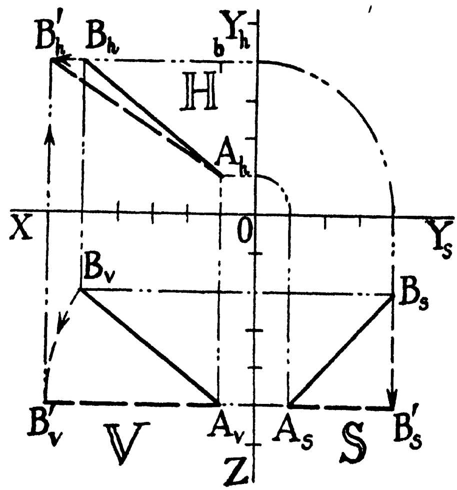


FIG. 25.

shown as full lines and the projections of the line after the rotation has occurred are shown by long dashes. See line 8 of Fig. 44, page 36, "position after movement."

In 𝕍, A_vB_v swings about A_v as a pivot until in its new position $A_vB'_v$ it is parallel to OX. In ℍ, B_h moves in a line parallel to OX (since in Fig. 24 the motion of B takes place entirely in the plane of bBB', which is parallel to 𝕍), and as B'_h must be vertically above B'_v the motion terminates where a line drawn vertically up from B'_v meets the horizontal line $B_hB'_h$. Joining A_h and B'_h, the new ℍ projection is the true length of the given line. The 𝕊 projection is of no interest in this case. The ℍ and 𝕍 projections of Fig. 25 show the graphical process corresponding to the theory of this rotation. In 𝕍, B_v moves to B'_v, whence a vertical pro-

jector meeting a horizontal line of motion from B_h determines B'_h, the new position of B_h. $A_hB'_h$ is the true length of the line. A second rarely used line of the "Alphabet of Lines," No. 14 of Fig. 44, page 36, is seen here, the "Line of Motion," appearing at $B_vB'_v$ and $B_hB'_h$. Arrowheads are often used to show the direction of motion, and they are also often put on construction lines such as $B'_vB'_h$ in Fig. 25 to show the direction followed in the drafting process. The S views in Figs. 24 and 25 are unnecessary.

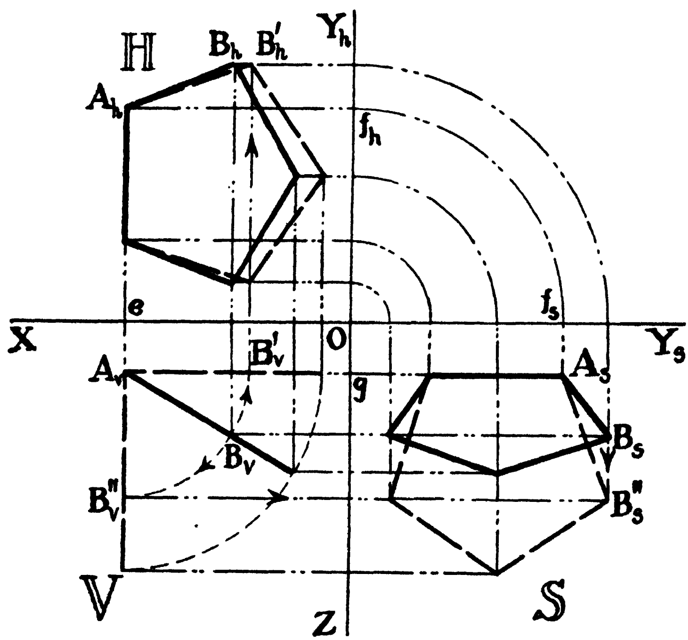


FIG. 26-A.

33. Variations in the Method.—The method is subject to wide variations. The same projector-plane AA_vB_vB, Fig. 24, revolving about the same projector AA_v, might start in the opposite direction and swing to a position parallel to S. The graphical process of Fig. 25 would then confine itself to V and S instead of V and H.

In addition, the rotation might have been about BB_v as an axis or about the V projector of any point in AB or AB extended.

Finally, the H projector-plane or the S projector-plane might have been selected and made to revolve into position. There are six distinct varieties of the process, each one subject to great modifications.

34. The True Shape of a Plane Figure by Revolving It.—Just as the method of finding the *true length of a line* by projection

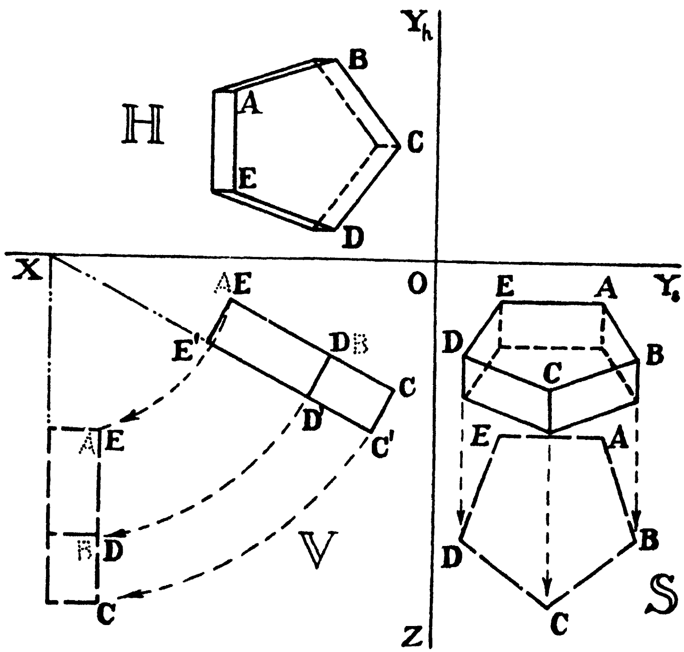


FIG. 26-B.

upon a U-plane is applied in practice to finding the *true shape of a plane figure* so this method also is applied in a wholesale manner.

In Fig. 26-A a polygon *ABCDE* is seen on edge on V. Using AA_v, a projector, as a hinge, the polygon may be swung down until parallel to S, or up until parallel to H. (In practice both would not be done.) Some point other than A_v may be chosen as the center of rotation, of course.

In Fig. 26-B the polygon of Fig. 26-A is represented as one end of a short prism. The corresponding points at the other end are

the points A', B', etc., some of which have been marked on the figure. The line $E'_vD'_vC'_v$ has been extended back to the axis of X, at X, and that point used as the center for the rotation shown.

Students often find the representation of a solid figure more easily grasped than that of a plane of no thickness. In such cases 26-B may aid 26-A to give its message.

For finding the true shape the method of *rotation* is not so much used as the method of *projection on a U-plane.* In Fig. 26-B a center of rotation had to be very carefully chosen to make the new position of the prism on S fall clear of the old position. It is often impossible to avoid overlapping.

The processes have two steps in common. In using the U-plane the figure is *projected to a parallel plane* and then *rotated* into coincidence with a regular plane of projection. In getting the true shape by revolving the plane figure is *rotated until parallel to a regular plane of projection* and then *projected* upon it.

35. A Projector-Plane Used as an Auxiliary Plane of Projection. —In Fig. 23 the V projector-plane of the polygon might have been taken as itself the U-plane for showing its own true shape. It would result in moving XM to the right until it overlapped A_v. This would carry XN_h close up to A_h and crowd the views. Perfectly correct results would be given. The whole U-plane would be a little closer in toward the origin. Danger of overlapping of views keeps this from being a common practice, however. In drawing we want the maximum of clarity.

Problems II.

30. A square in a position similar to the pentagon of Fig. 26 has the corners A (10, 12, 2), B (2, 12, 8), C (2, 2, 8) and D (10, 2, 2). Find its true shape by the use of an auxiliary plane.

31. A square is in a position similar to the pentagon of Fig. 23. The corners are A (9, 3, 3), B (9, 13, 3), C (3, 13, 11), and D (3, 3, 11). Find its true shape by revolving into a plane parallel to H.

32. Plot the triangle A (11, 3, 2), B (12, 6, 12), C (14, 12, 7).

Find its true shape by the use of an auxiliary plane perpendicular to $\mathbb{H}$.

33. Plot the triangle A (13, 15, 8), B (10, 11, 0), C (7, 7, 8). Find the true shape of the triangle by revolving it about AA_h until in a plane parallel to $\mathbb{S}$. Find the true shape by projection on a plane $\mathbb{U}$, perpendicular to $\mathbb{H}$, whose inclined trace passes through the point (16, 0, 0).

34. Same with triangle A (9, 7, 8), B (12, 11, 13), C (15, 15, 2).

35. Plot the right triangle A (14, 4, 3), B (14, 10, 3), C (6, 4, 9). Revolve it about BB_v into a plane parallel to $\mathbb{H}$ and project its true shape on $\mathbb{H}$.

36. Plot the right triangle A (9, 3, 6), B (9, 3, 0), C (15, 11, 6). Revolve it about AB until in a plane parallel to $\mathbb{V}$ and plot C', the new position of the vertex. Revolve it about the same axis into a plane parallel to $\mathbb{S}$, and plot C'', the new position of the vertex.

37. Plot the square A (14, 8, 2), B (11, 14, $7\frac{1}{3}$), C (11, 2, $7\frac{1}{3}$), D (8, 8, $12\frac{2}{3}$). The diagonal is 12 units long. Revolve the square about AA_v into a plane parallel to $\mathbb{H}$, and project its true shape on $\mathbb{H}$.

38. Plot the triangle A (12, 2, 14), B (2, 2, 14), C (7, 7, 2). Revolve it about AB into a plane parallel to $\mathbb{V}$, and project the true shape on $\mathbb{V}$. On coordinate paper or blackboard show the true shape by projection on an auxiliary plane $\mathbb{U}$ perpendicular to $\mathbb{S}$, through the point (0, 8, 0).

39. The triangle A (3, 7, 11), B (13, 2, 13), C (5, 2, 1) is a triangle in an oblique plane. Find its true shape as follows: BC appears at its true length in $\mathbb{V}$. Draw A_vD_v perpendicular to B_vC_v. AD is an oblique line, but it is perpendicular to BC since its $\mathbb{V}$ projector-plane AA_vD_vD is perpendicular to BC. Find the true length of AD by any method. On $\mathbb{V}$ extend A_vD_v to E_v, making D_vE_v equal to the true length of AD. $E_vB_vC_v$ is the true shape of the triangle ABC.

CHAPTER III.

PLANE SURFACES AND THEIR INTERSECTIONS AND DEVELOPMENTS.

36. The Omission of the Subscripts h, v, **and** s.—In a descriptive drawing a point does not itself appear but is represented by its projections on the reference planes. This fact has been emphasized in the previous chapters. In the more complicated drawings which now follow it will save time and will prevent overloading the figures with lettering, to omit the subscripts h, v, and s, and to refer to a point and its projections by the same letter. Thus "A_v" or "the point A in V" are expressions which call attention to the projection of A on V, but a diagram will show only the letter A at that place. If at any time it is necessary to be more precise the subscripts may be restored. They should be used if any confusion is caused by their omission.

If the projections of two points coincide, it is sometimes advisable to indicate which point is behind the other in that view by forming the letter of fine dots. Referring back to Fig. 16, the projections of A and B on S coincide. On this system subscripts are omitted and the letter B (on S only) is formed of dots, as in Fig. 27.

37. Finding Where a Given Line Pierces a Given Plane.—Many machine parts have plane faces, each face a polygon. Problems of intersection continually arise requiring the repetition of a fundamental process, that of finding where a given line pierces a given plane. The practical rule is to search always for a view, H, V, S or U, as the case may be, in which the given plane is "seen on edge." (It may be necessary to construct a U-plane for the purpose.) On that view note where the given line intersects the line representing the plane. It is the true point of piercing. Once identified (and lettered) the point is then projected to other views as may be needed.

38. A Pyramid Cut by a Plane.—As a simple example let us suppose that it is required to find where a plane perpendicular to V, and inclined at an angle of 30° with H, intersects an hex-

agonal pyramid with axis perpendicular to H. Fig. 27 is the drawing of the pyramid, having the base *ABCDEF* and vertex *P*. The cutting plane is an inclined plane such as we have used for an auxiliary plane, and its traces are therefore similar to those of an auxiliary plane. *KL* is the inclined trace on V and *KK'* and *LL'* are the traces parallel to the axis of *Y*. The problem is to find the shape of the polygonal intersection *abcdef* in H and S, and its true shape.

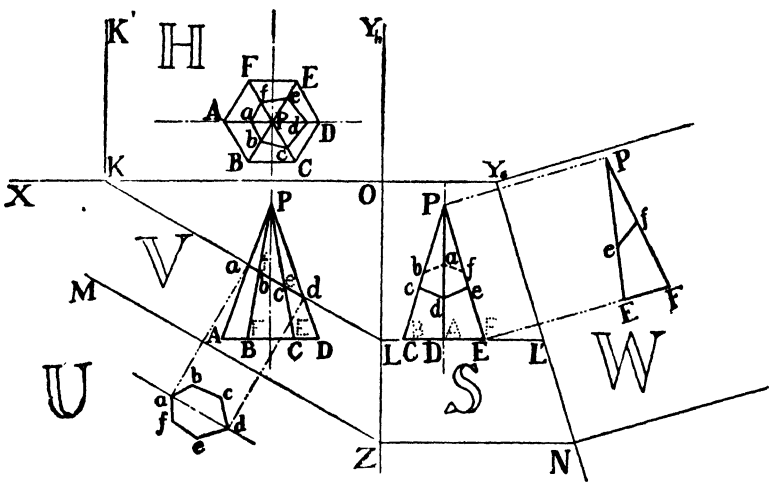


FIG. 27.

The method of solution of all such problems is to take into consideration each edge of the pyramid in turn, and to trace the points where they pierce the plane. Thus, the edge *PA* pierces the given plane at *a*, whose projection on V is first located; for the given plane is *seen on edge* in V, and *PA* cannot pierce the plane at any other point consistent with that condition. *a*, once located in V, can be projected horizontally to the line *PA* in S and vertically to *PA* in H.

The true shape of the polygon *abcdef* may be shown on an auxiliary plane, U, whose traces are *ZM* and *ZN*. In Fig. 27 the projection of the pyramid on U is incomplete. As it is only to show the polygon *abcdef* the rest of the figure is omitted.

39. Plotting Prisms and Pyramids.—Our next task is to make careful drawings of prisms and pyramids cut by planes, a wholesale application of Art. 38. We must first plot the prisms and pyramids in a systematic manner, in four orderly steps as follows:

a. Plot the ends of the axis of the solid first in all three views. That is, plot the vertex and the center of the base, or the centers of the two bases. Assign letter *P, P′, Q, Q′*, etc. Join the ends by a center line, or dash-dot line.

b. Draw the traces of the planes of bases rather faintly in pencil, and in excess of the length probably required.

c. Draw the true shape of the base or bases. This must be done on that plane, $\mathbb{H}$, $\mathbb{V}$ or $\mathbb{S}$, which may be parallel to the base. If none is parallel pass a new plane, $\mathbb{U}$, parallel to the base and draw the true shape on it. Letter corners of the bases *A, B, C*, etc., *A′, B′, C′*, etc.

d. Draw the side edges of the prism or pyramid. Letter the side edges of a prism, *AA′, BB′*, etc. Letter the side edges of a pyramid *PA, PB*, etc.

Any problem in this course of instruction, or found later in applying the subject to engineering practice, will have the data for the four steps in some way embodied in its statement. It is necessary to look for the four items, rearrange them, and plot in the order given, unless every corner is given fully by coordinates.

40. Development of a Pyramid or Prism.—A development of the plane faces of a solid is like the development of the planes of projection as shown on page 211, Art. 5. We conceive some edges of the solid to be split open and others to be used as hinges, finally flattening all the surfaces into one plane *without distortion.*

As the choice of edges to slit, and edges to use as hinges, is quite large there are a great many possible arrangements of each development. Each face, however, is preserved in its true shape.

Consider now the development of the pyramid of Fig. 27, p. 246, with the intersection with the plane *KL* marked on its surfaces.

Let us consider the pyramid to be slit along the edge *PA* and around the base, except *FA*, and all the other edges used as hinges. The net result is the development shown in Fig. 27-*B*. Every face must be a true shape. The true shape of the base *ABCDEF* is

found on $\mathbb{H}$ of Fig. 27, though we see here the bottom view of it, not the top. The true length of PA (and of Pa) is found on $\mathbb{V}$. The face PAB may be constructed knowing PB to equal PA in length. Simply lay off PA of its true length. With P as center and PA as radius describe a circle on which the length AB can be stepped off six times for the six equal sides of the hexagon. Were it not a regular hexagon each face would have to be constructed individually. Having joined P with the points B, C, D, E, F and A, we lay off Pa again, and Pd from its true length on $\mathbb{V}$ of Fig. 27. It remains to find true lengths of Pb, Pc, Pe and Pf. This has been done in Fig. 27 by taking an auxiliary plane $\mathbb{W}$ perpendicular to $\mathbb{S}$ and parallel to PEF on $\mathbb{V}$. This shows the whole face PEF in its true shape. Any other way of getting true lengths of Pe and Pf (and their equals Pb and Pc) would be a legitimate substitute for plane $\mathbb{W}$.

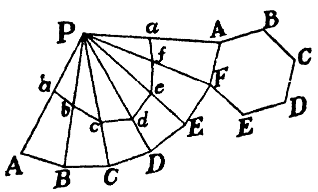


FIG. 27-B.

A prism is developed in exactly the same manner. It is usually easier than the pyramid. One must always remember that a development is a collection of true shapes and no lines can appear foreshortened, nor angle or area distorted. In practical drawing the *outside views* of the surfaces are shown.

Résumé of Chapters I to III.—The important subjects so far treated are:

1. The meaning of orthographic projection and the standard requirement of projections or views on three mutually perpendicular planes.

2. The need for views to be not only correct in themselves but correctly related to adjacent views, according to the three laws of projection.

3. How to discriminate between a quadrilateral and a tetrahedron. Concealed edges.

4. Names and definitions of kinds of lines and planes. How to identify that view on which a line is shown without foreshortening.

5. Use of an auxiliary plane of projection, to get the true length

of a line which is foreshortened in all three regular views, or to get the true shape of a plane figure whose plane is inclined.

6. The fourth law of projection or " rule of the missing coordinate" as used to construct projections on the " U-plane."

7. The true length and true shape by revolving a line or area about a projector until parallel to H, V or S.

8. How to determine where a given line pierces a given plane. Application to planes cutting prisms and pyramids.

9. Developments of prisms and pyramids, considered as a collection of true shapes of all surfaces of a solid in one view.

Problems III.

(For use on cross-section paper or blackboard.)

40. Plot the projections of the points A (9, 3, 16), B (6, 3, 16), C (6, 8, 16), D (9, 8, 16), and E (0, 3, 4), F (0, 3, 8), G (0, 8, 8), H (0, 8, 4). Join the projections A to E, B to F, C to G, etc. Show how to find the true shape of every plane surface of the solid (a prism) thus formed. On cross-section paper or on blackboard show how to draw the development of the surface of the solid.

41. Same as Problem 40, with points A (10, 8, 0), B (8, 10, 0), C (12, 14, 0), D (14, 12, 0) on H and E (10, 8, 16), F (6, 12, 16), G (8, 14, 16), H (12, 10, 16) on H′. (In developing the surface, find the true shape of the quadrilateral $BFGC$ by dividing it into two triangles by a diagonal BG whose true length will appear on S. Divide $CGHD$ by the diagonal CH.)

42. Draw the tetrahedron whose four corners are A (16, 2, 13), B (6, 2, 13), C (11, 14, 13) and D (11, 7, 1). It is intersected by a plane perpendicular to V cutting V in a trace passing through the origin, making an angle of 30° with OX. Draw the trace of the plane on V. Where are its traces on H and S? Show the H and S projections of the intersection of the plane and tetrahedron.

43. A solid is in the form of a pyramid whose base is a square of 10 units, and whose height is 8 units. The corners are A (16, 2, 10),

B (10, 2, 2), *C* (2, 2, 8) and *D* (8, 2, 16) and the vertex *E* (9, 10, 9). It is intersected by a plane perpendicular to $\mathbb{H}$, whose trace on $\mathbb{H}$ passes through the origin, making an angle of 30° with *OX*. Draw the $\mathbb{V}$ and $\mathbb{S}$ projections of the intersection of the pyramid and plane. Where is the trace of the cutting plane on $\mathbb{V}$?

44. Draw the development of the tetrahedron of Problem 42 with the line of intersection marked on it.

45. Draw the development of the pyramid of Problem 43 with the line of intersection marked on it.

Sheets 5 and 6, described on pages 361 to 363, are designed to be executed at this place in the study of the subject.

CHAPTER IV.

INTERSECTING PRISMS AND PYRAMIDS.

41. Steps in Solving Complex Problems of Intersecting Prisms and Pyramids.—Hitherto we have dealt with a prism or a pyramid and a *single intersecting plane.* We found the points where edges of the prism or pyramid pierced the plane by finding a view on which the given plane was represented by a line only.

We now deal with complex cases where two solids intersect. Each solid is intersected by a *group of planes* namely by the plane faces of the other solid. Moreover, the intersecting planes are themselves limited in extent. The plan of attack we need for such cases consists of four steps as follows:

1. *Plot the two solids* as regards all parts which do not intersect. Letter all corners according to plan. Draw very faintly edges which may intersect.

2. *Find the Points of Intersection.* Consider one by one the lines of one solid. If an edge seems to pierce the other solid look to that view of the second solid on which the face which seems to be pierced is seen on edge. Mark where it pierces with a descriptive letter, and immediately project such a point of piercing to the other views and letter it there. It is likely to go through the solid and come out again. Look for the second point and mark it. Do this for every line of solid, No. 1, then for every line of solid, No. 2.

3. *Find Lines of Intersection.* When all piercing points are found and lettered a systematic examination will disclose two such points which can be proved to be on two planes, one a face of one solid and the other a face of the other. When that is done the points in question are the ends of a (limited) line of intersection of the two (limited) planes. The complete line of intersection is, generally, one or two "warped polygons." A warped polygon consists of four or more straight lines not all in the same plane.

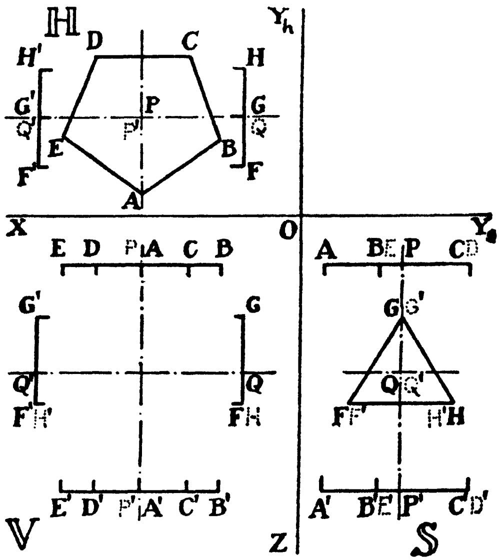


FIG. 28.

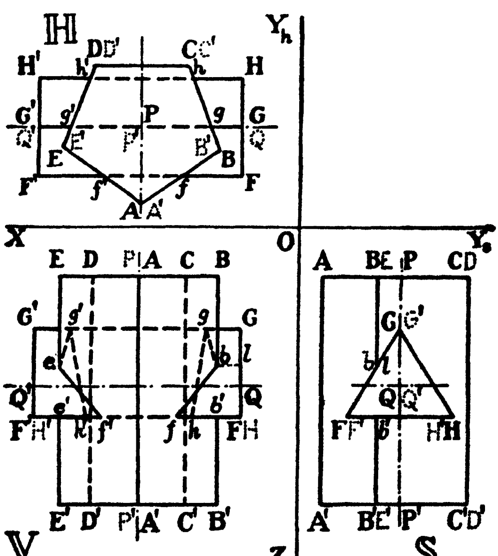


FIG. 29.

4. *Reconsider all Interior Lines,* as to whether full, broken, partly broken or partly obliterated.

Application to the problem of two intersecting prisms whose axes are parallel to the axes of X and of Z is shown in Figs. 28 and 29. The vertical prism is pentagonal and has as axis the line PP'. The horizontal one is triangular and its axis is QQ'.

In Fig. 28 the steps a, b and c of Art. 39 have been carried out and the corners of all bases lettered in all three views systematically. The problem is to complete to the condition shown in Fig. 29, assuming prism QQ' to "pierce PP'."

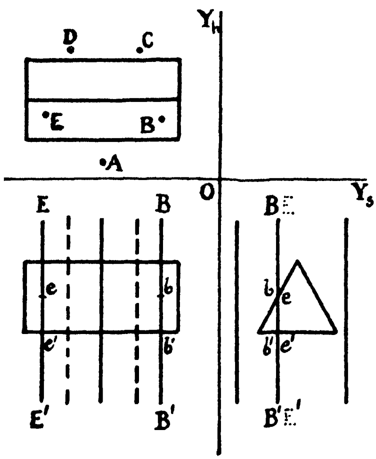


FIG. 30-A.

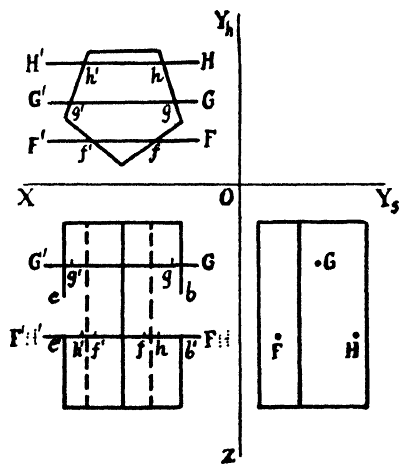


FIG. 30-B.

42. Points of Intersection.—The second step is to find the points of intersection. Faintly draw the side edges of prism PP'. Confine attention to these side edges and the faces of prism QQ', or to so much of the drawing as is shown in Fig. 30-A. We see on the plan that AA', CC' and DD' entirely clear the prism, QQ', *and that* BB' and EE' pierce it. We see on $\mathfrak{S}$ where BB' and EE' pierce the faces of QQ' and letter b, b', e and e' there. From $\mathfrak{S}$ we project to corresponding lines on $\mathfrak{V}$, b and b' to BB' and e and e' to EE'.

We may anticipate here one feature of the fourth step. Since QQ' pierces PP' part of PP' has been destroyed by cutting a hole through it. The edges bb' and ee' are on the part destroyed and

may be immediately erased as shown in Fig. 30-B.

To go on with the second step, consider next the side edges of QQ' and the faces of PP', confining attention to the parts shown on Fig. 30-B. We see on $\mathbb{S}$ that FF', GG' and HH' all pierce PP'. On $\mathbb{H}$, the faces of PP' are seen on edge as lines and we easily locate and letter these the points f, f', g, g', h, and h'. We project them down to $\mathbb{V}$ each to its proper line and letter them there as shown. The whole set of piercing points are now recorded on $\mathbb{V}$. They form two warped polygons, as shown on Fig. 29. We must have a reason for connecting up the points as shown.

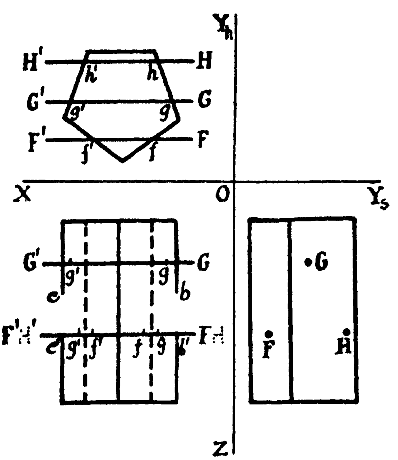


FIG. 30-B. (Repeated)

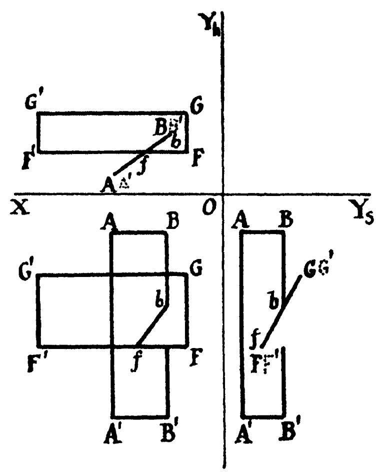


FIG. 30-C.

43. Lines of Intersection.—Each line is the intersection of two finite plane surfaces. For example in Fig. 30-C two surfaces $ABB'A'$ of PP' and $FGG'F'$ of QQ', have been drawn dissociated from all the other faces. Point b is a point on both planes. It is a point on BB', therefore on the plane $ABB'A'$. It is a point on $FGG'F'$ as seen on the $\mathbb{S}$ projection where that plane is on edge. Similarly, point f is on FF', therefore on $FGG'F'$. It is also on $ABB'A'$ as seen on $\mathbb{H}$ where that plane is "on edge." Join f and b. fb is the line of intersection of the two planes considered.

To trace out the warped polygon $fbghb'f$ it is best to keep one of the two planes just considered, say $FGG'F'$ and to change the

other to an adjacent plane. Let us shift from $ABB'A'$ to $BCC'B'$. We must prove that b and g are on both planes and that bg is their line of intersection, which must be drawn on $\mathbb{V}$, Fig. 29. The student should reason this out for himself. By symmetry join $f'e$ and eg'.

44. Meaning of Piercing.—Our original statement was that QQ' pierces PP'. Since two objects cannot occupy the same space we must assume that a hole has been cut in the prism PP' just of the size to allow the prism QQ' to be pushed through. QQ' is complete and perfect. Therefore gg', ff' and hh' are broken lines representing concealed parts of the edges GG', FF', and HH'.

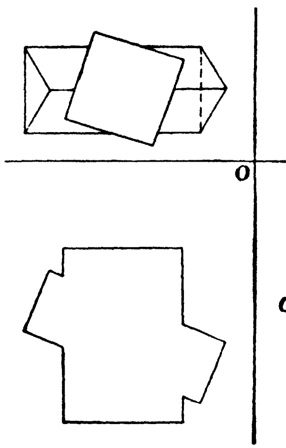


FIG. 31.

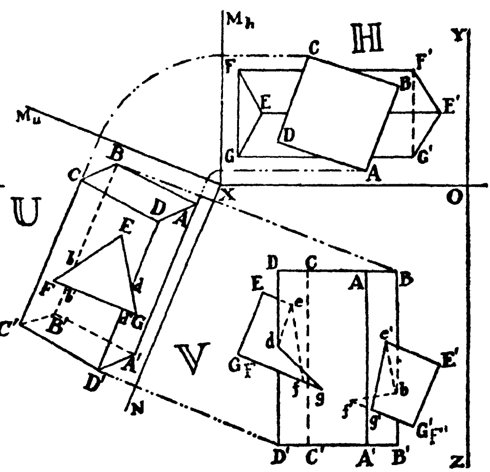


FIG. 32.

We erased bb', a part of the edge BB' of the prism PP', because it must have been destroyed in cutting a triangular hole in PP' for QQ' to be put in place.

Had the object been described as one solid instead of two separate pieces, the lines gg', ff' and hh', like bb' and ee', would be erased.

45. Use of an Auxiliary Plane of Projection.—To find the intersection of solids composed of plane faces, it is essential to have views in which the various plane faces are seen on edge. To obtain such views auxiliary planes of projection are often needed.

Fig. 31 shows the layout of a problem which requires an auxiliary

view on U in order to show the side planes of the triangular prism "on edge." (Two of these planes are oblique, not inclined, and therefore do not appear on edge on any reference plane.) Fig. 32 shows the complete solution, the object drawn being one solid piece and not one prism piercing another. *b* and *d* are located by the use of the view on U. In this case and in many similar cases in practical drawing, the complete view on U need not be constructed. The use of U is only to give the positions of *b* and *d*, which are then projected from U to V. (*b′* and *d′* can be found directly on V as well as on U.) The construction on U of the square ends of the vertical prism is superfluous and would be omitted in practice.

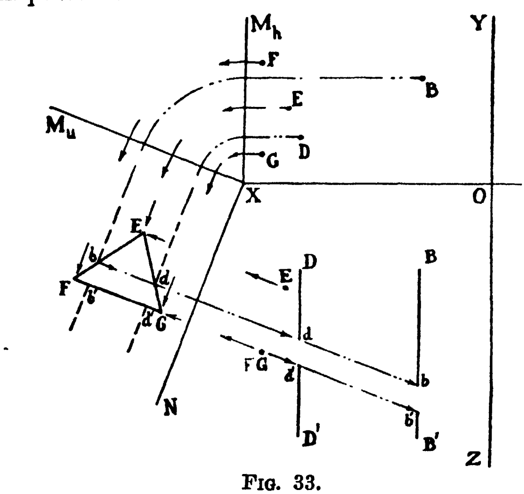


FIG. 33.

Fig. 33 shows the part of the view on U which must be constructed. It shows also how the U view is obtained by projection from five points on H, namely *B, D. E, F* and *G*, and from two points on V, namely *E* and *G*. Arrows show these projections and arrows show also the projection of *b, d, b′* and *d′*, when found, from U to V.

46. Development of a Prism.—It is often desired to show the true shape of all the plane surfaces of a solid object in one view, keeping the adjacent faces in contact as much as possible. This is called *developing the surface on a plane*, and is particularly useful for all

objects made of sheet metal, as the development forms a pattern for cutting the metal, which then requires only to be bent into shape and the edges to be joined or soldered.

The two prisms of Fig. 29 afford good subjects for development. Fig. 34 shows the developed surface of the triangular prism, the lines *g-g* and *g′-g′* showing the lines of intersection with the other prism. In this figure it is considered that the surface of the triangular prism is cut along the lines *GG′*, *GF*, *G′F′*, *GH*, and

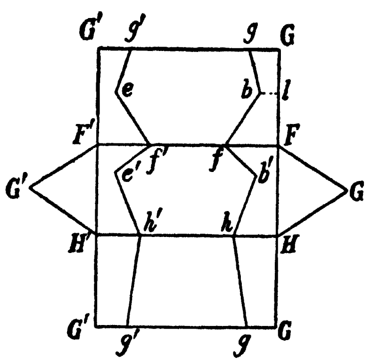


FIG. 34.

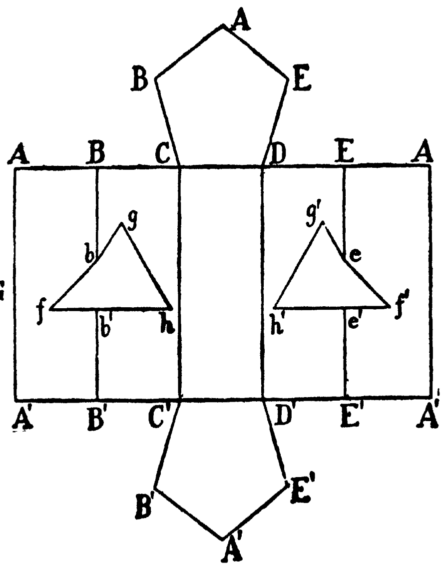


FIG. 35.

G′H′; and the other planes unfolded, using *FF′*, *FH*, etc., as hinges, until all coincide with *FF′H′H*. Since *outside views* are wanted, note that *FF′H′H* is the mirror image of *FF′H′H* as shown on **H**, Fig. 29, page 252, because it is now seen *from below*.

Fig. 35 shows the development of the large prism of Fig. 29, with the holes where the triangular prism pierces it when the two are assembled. The surface of the prism is cut on the line *AA′*, and on the other lines as needed, and the surfaces are flattened out by unfolding on the edges not cut.

The construction of these developments is simple, since the sur-

faces are all triangles or pentagons whose true shapes are given; or are rectangles, the true length of whose edges are already known.

In Fig. 34 the distances GG, $G'g'$, Ff, $F'f'$ are taken directly from $\mathbb{V}$ in Fig. 29. The points b and e are plotted as follows: The perpendicular distance bl to the line GF is taken from $\mathbb{V}$, Fig. 29, and Gl is taken from Gl in $\mathbb{S}$, Fig. 29. The other points are plotted in the same manner. The true shape of any quadrilateral can be drawn if the true lengths of all four sides *and one diagonal* are known.

Problems IV.

46. A plane, $\mathbb{H}'$, is parallel to $\mathbb{H}$ at 16 units from $\mathbb{H}$. A square prism has one base in $\mathbb{H}$, corners A (8, 2, 0), B (3, 7, 0), C (8, 12, 0), D (13, 7, 0). The other base, $A'B'C'D'$ lies in $\mathbb{H}'$ A' has the coordinates of A except z coordinate which is 16.

A plane, $\mathbb{S}'$, is parallel to $\mathbb{S}$ at 16 units from $\mathbb{S}$. A triangular prism has base E (0, 5, 8), F (0, 13, 2), G (0, 13, 14) in $\mathbb{S}$ and base $E'F'G'$ in $\mathbb{S}'$. The x coordinates of E', F' and G' are 16.

Make the drawing of the intersecting prisms with prism EFG solid and inserted in a triangular hole cut in prism $ABCD$.

47. A sheet-iron coal chute connects a square port, A (2, 4, 2), B (2, 12, 2), C (2, 12, 10), D (2, 4, 10), with a square hatch, E (14, 6, 16), F (14, 10, 16), G (10, 10, 16), H (10, 6, 16).

The problem is to draw the chute and the development of the four plates necessary to form it.

The corners are the lines AE, BF, CG and DH. The top sheet, $AEFB$, and the bottom sheet, $DHGC$, are planes perpendicular to $\mathbb{V}$. To find their true shapes apply Art. 34, page 240.

The side sheets are not planes but warped polygons. For example the plate $AEHD$ must be bent slightly on the line AH. The triangle ADH is an inclined plane perpendicular to $\mathbb{H}$ and the other triangle AHE is an inclined plane perpendicular to $\mathbb{S}$. Find the true length of AH by applying Art. 32, page 238. The whole development is, then, the true shapes of two quadrilaterals and four triangles.

48. Draw the development of the square prism of Problem 46, with the lines of intersection marked on it. These are holes to be cut out of the metal sheet.

49. Draw the development of the triangular prism of Problem 46 with the lines of intersection marked on it.

Sheets 7 and 8, described on pages 364 to 367, are designed to be executed at this place in the study of the subject.

CHAPTER V.

SIMPLE CURVED LINES AND SURFACES.

47. The Simplest Plane Curve, the Circle.—The geometrical natures of the common curves are supposed to be understood. Descriptive Geometry treats of the nature of their orthographic projections. The curves now considered are plane curves, that is, every point of the curve lies in the same plane. It is natural, therefore, that the relation of the plane of the curve to the plane of projection governs the nature of the projection.

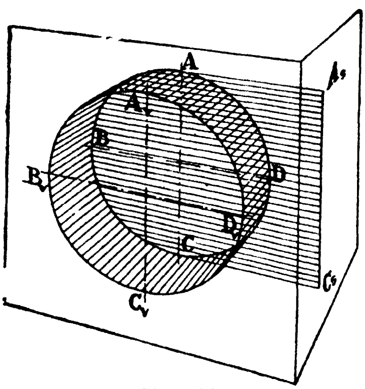


FIG. 36.

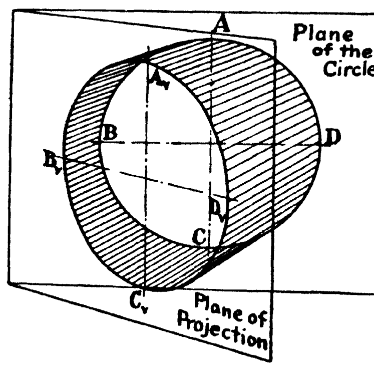


FIG. 37.

The simplest plane curve is a circle. Figs. 36 and 37 show the three forms in which it projects upon a plane. In Fig. 36, a perspective drawing, we have a circle projected upon a parallel plane of projection (that in the position customary for $\mathbb{V}$). The projectors are of equal length and the projection is itself a circle exactly equal to the given circle.

On a second plane of projection (that in the position of $\mathbb{S}$) perpendicular to the plane of the circle the projection is a straight line equal in length to the diameter of the circle, AC. The projectors for this second plane of projection form a projector-plane.

In Fig. 37 the circle is in a plane inclined at an angle to the plane of projection. The projectors are of varying lengths. There must be one diameter of the circle, however, that marked AC, which is parallel to the plane of projection. The projectors from these points are of equal length, and the diameter AC appears of its true length on the projection as A_vC_v.

The diameter BD at right angles to AC, has at its extremity B the shortest projector, and at the extremity D the longest projector. On the projection, BD appears greatly foreshortened as B_vD_v, though still at right angles to the projection of AC and bisected by it.

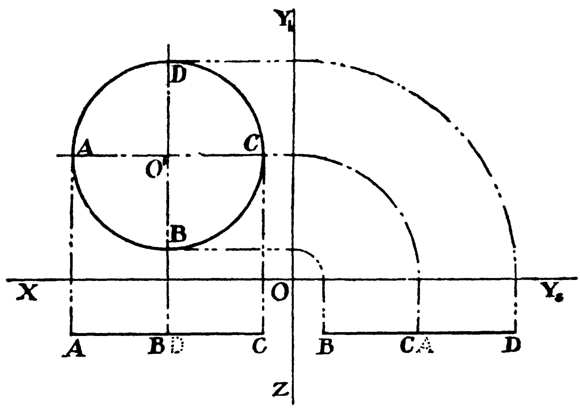


FIG. 38.

The true shape of the projection is an ellipse, of which A_vC_v is the major axis and B_vD_v is the minor axis. No matter at what angle the plane of projection lies, the projection of a circle is an ellipse whose major axis is equal to the diameter of the circle.

For convenience the two planes of projection in Fig. 36 have been considered as $\mathbb{V}$ and $\mathbb{S}$, and the projections lettered accordingly. The plane of projection in Fig. 37 has been treated as if it were $\mathbb{V}$, and the ellipse so lettered. It must be remembered that the three forms in which the circle projects upon a plane, as a circle, as a line, and as an ellipse, cover all possible cases, and the relations between the plane of the circle and the plane of projection shown in the two figures are intended to be perfectly general and not confined to $\mathbb{V}$ and $\mathbb{S}$ alone.

48. The Circle in a Horizontal or Vertical Plane.—Passing now to the descriptive drawing of a circle, the simplest case is that of a circle which lies in a plane parallel to $\mathbb{H}$, $\mathbb{V}$ or $\mathbb{S}$. The projections are then of the kind shown in Fig. 36, two projections being lines and one the true shape of the circle. Fig. 38 shows the case for a circle lying in a horizontal plane. The true shape appears in $\mathbb{H}$. The $\mathbb{V}$ projection shows the diameter AC, the $\mathbb{S}$ projection shows the diameter BD.

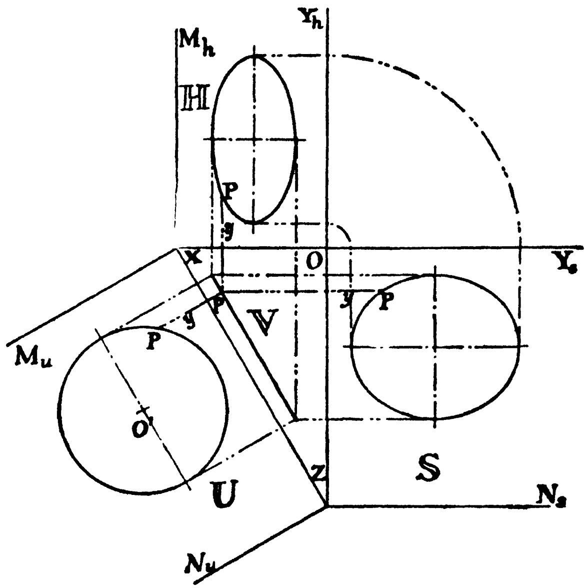


FIG. 39.

49. The Circle in an Inclined Plane.—Fig. 39 shows the circle lying in an inclined plane, perpendicular to $\mathbb{V}$, and making an angle of 60° with $\mathbb{H}$. The $\mathbb{V}$ projectors, lying in the plane of the circle itself, form a projector-plane and the $\mathbb{V}$ projection is a straight line equal to a diameter of the circle. As the plane of the circle is oblique to $\mathbb{H}$ and $\mathbb{S}$, these projections on $\mathbb{H}$ and $\mathbb{S}$ are ellipses whose major axes are equal to the diameter of the circle. Of course, for any point of the curve, as P, the laws of projection hold, as is indicated. The true shape of the curve can be shown by

projection on any plane parallel to the plane of the circle. It is here shown on the auxiliary plane $\mathbb{U}$, taken as required. If the drawing were presented with projections $\mathbb{H}$, $\mathbb{V}$ and $\mathbb{S}$, as shown, one might at first suspect that it represented an ellipse and not a circle; but, if a number of points were plotted on $\mathbb{U}$, the existence of a center O' could be proved by actual test with the dividers.

50. The Circle in an Oblique Plane.—When a circle is in an oblique plane, all three projections are ellipses, as in Fig. 40. The noticeable feature is that the three major axes are all equal in length.

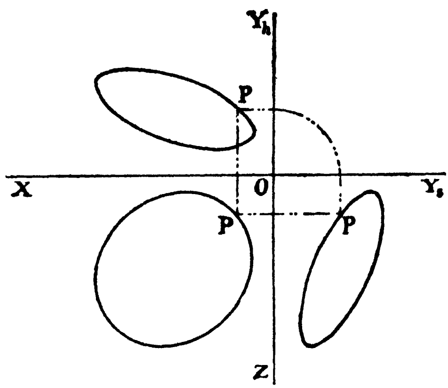


FIG. 40.

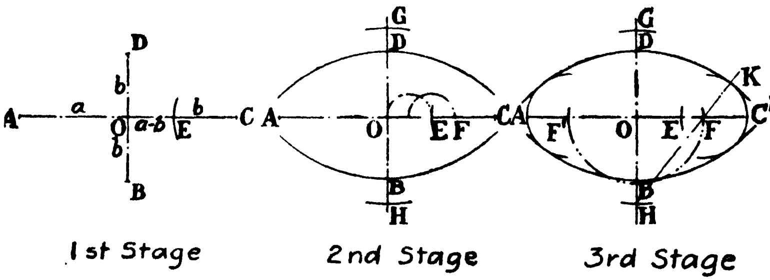
When an *ellipse* is in an oblique plane, its three projections are also ellipses, but the major axes will be of unequal lengths. The proof of this fact must be left until later. The fact that the three projections have their major axes equal must be taken at present as sufficient evidence that the curve itself is a circle.

51. The Ellipse: Approximate Representation.—The ellipse is little used as a shape for machine parts. It appears in drawings chiefly as the projection of a circle. Some properties of ellipses are very useful and should be studied for the sake of reducing the labor of executing drawings in which ellipses appear.

An approximation to a true ellipse by circular arcs, known as the "draftsman's ellipse," may be constructed when the major axis $2a$ and the minor axis $2b$, Fig. 41, of an ellipse are known.

If b is two-thirds of a or over follow Art. 130 of Part I. Fig. 41 is repeated here as a reminder of that process.

52. Exact Plotting of the Ellipse.—For narrow ellipses plot points as described on pages 103, 170 and 171. Figs. 42 to 44, repeated here, are reminders of those processes.



THE "DRAFTSMAN'S ELLIPSE."
FIG. 41.

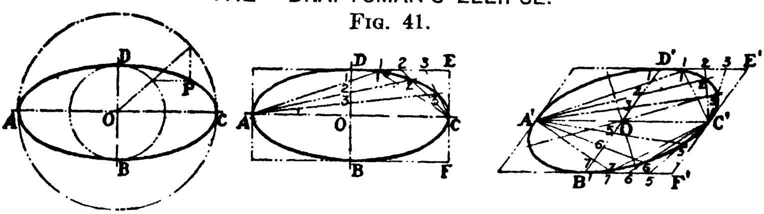


FIG. 42. FIG. 43. FIG. 44.

53. The Curved Line in Space.—A curve in space may sometimes be required, one which follows no known mathematical law, but which passes through certain points given by their coordinates. For example, in Fig. 45, four points, A (12, 1, 9), B (5, 4, 6), C (2, 4, 4) and D (2, 5, 1), were taken as given and a "smooth curve," the most natural and easy curve possible, has been passed through them. It is fairly easy to pass smooth curves through the projections of the 4 points on each reference plane, but it is essential that not only should the original points obey the laws of projection of Art. 11, but every intermediate point as well. The views must check therefore point by point and the process of tracing the curve must be carried out about as follows: The projections of the 4 points on $\mathbb{V}$ and $\mathbb{S}$ are seen to be more evenly extended than those on $\mathbb{H}$, and smooth curves are made to pass

through them by careful fitting with the draftsman's curves. The view on H cannot now be put in at random, but must be constructed to correspond to the other views. To fill in the wide gap between A_h and B_h an intermediate point is taken, as E_v on A_vB_v. By a horizontal line E_s is defined. From E_v and E_s the H projection (E_h) is plotted by the regular method of checking the projections of a point. As many such intermediate points may be taken as may seem necessary in each case.

To define the sharp turn on the curve between C_h and D_h, one

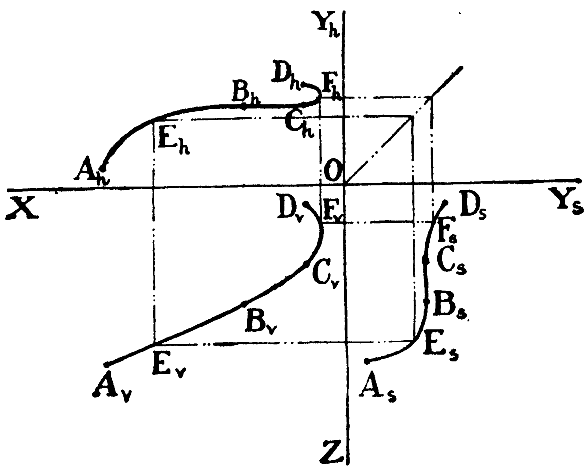


FIG. 45.

or more extra points, as F_h, should be plotted from the V and S projections. Thus every poorly defined part is made definite and the views of the line mutually check. The work of "laying out" the lines of a ship on the "mold-loft floor" of a shipbuilding plant includes work of this kind, in plotting the gunwale, etc.

54. Lines Representing Curved Edges.—Sharp edges we are familiar with. They show as lines, full or broken, on all the views, H, V, S and U. A line may reduce to a single dot, if seen on end, but a sharp edge appears in some form on all views.

The gradually curving edges of such surfaces as cylinders, cones and spheres, which we treat of in this chapter are different. The curved edge is the line which separates the part of the subject

which is in front and therefore visible, from the part behind which is not visible. As we move our position, this outline, separating the visible from the invisible, changes its position.

A curved edge may show on one plane of projection but never on all views.

55. Application to the Right Circular Cylinder.—In Fig. 46 we have in perspective a cylinder and a plane parallel to its axis,

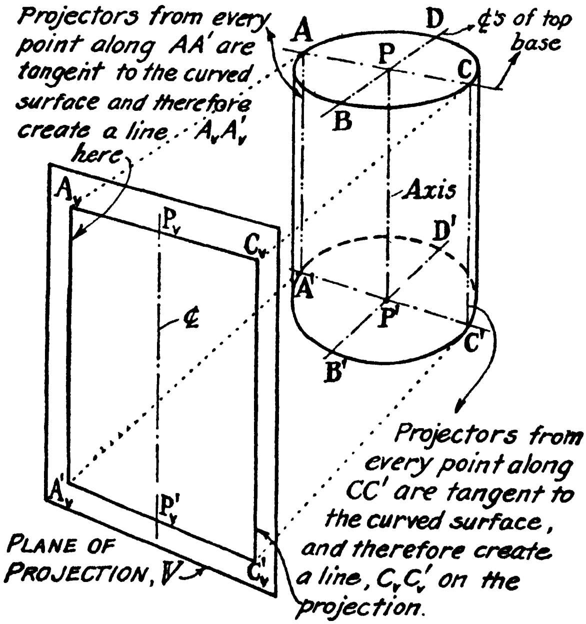
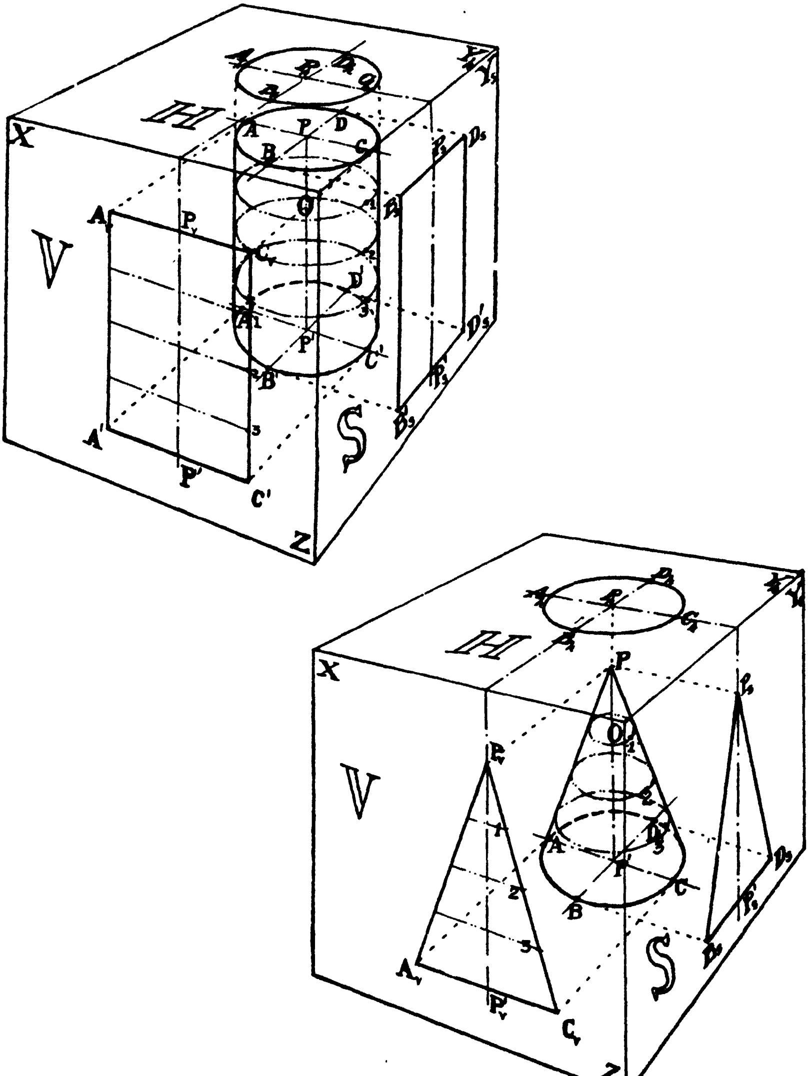


FIG. 46.

marked for convenience as a V plane. The cylinder is projected orthographically, upon the plane by the projectors shown as lines of dots. The sharp edges of the bases appear as lines A_vC_v and $A'_vC'_v$.

A plane parallel to V, containing the axis PP', will cut the cylinder in two straight lines AA' and CC'. These lines separate the part of the cylinder $ABCC'B'A'$, which is visible from V, from the part $ADCC'D'A'$, which is invisible. AA' and CC' are the curved edges as seen from V.



FIGS. 47 and 48.

Projectors to **V** from every point along CC' and AA' are lines *tangent to the curved surface.* Such tangent projectors by common

consent are supposed to impress an image upon the plane of projection. Projectors from points on the surface which are not tangent make no impress on the plane. This distinction is called the *principle of tangent projectors.*

Fig. 47 is a perspective of a cylinder in its three usual views. Fig. 49 is the descriptive drawing, the development of Fig. 47. We have assumed that the student is familiar with the idea that a right circular cylinder may be generated by revolving a straight line, such as AA', about a parallel straight line PP'. As it revolves

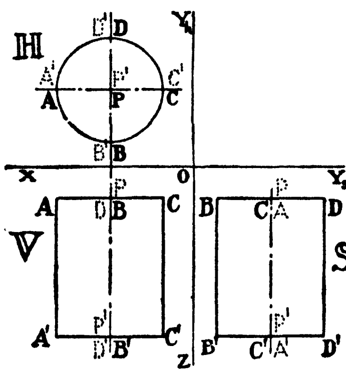


FIG. 49.

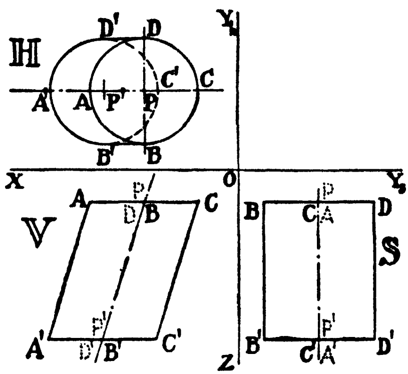


FIG. 50.

AA' takes the position of DD', CC', BB' and intermediate stations in turn.

Every possible position is called an "element" of the surface. Thus AA', BB' CC' etc., are elements.

When the cylinder is projected upon V, AA' and CC' are the elements which appear in V because the V projectors of all points along those lines are tangent to the cylinder, as can be seen from the view on H. The elements which are represented by lines on S are BB' and DD'.

The right circular cylinder may also be considered as generated by moving a circle along an axis perpendicular to its own plane through its center.

In Fig. 47 consider the top base of the cylinder to be moved down the cylinder. Each successive position of the circle is a "circular element" of the cylinder. The circles through the points

1, 2, 3, etc., are simply circular elements of the cylinder taken at equal distances apart.

56. The Inclined Circular Cylinder.—Fig. 50 shows an *inclined circular cylinder.* It has circular and straight line elements as before, though it cannot be generated by revolving a line about another at a fixed distance, but can be generated by moving the circle *ABCD* obliquely to *A'B'C'D'*, the center moving on the axis *PP'*. The straight elements are all parallel to the axis. The cross-section of a cylinder is a section taken perpendicular to the axis. In this case the cross-section is an ellipse, and for this reason the Inclined Circular Cylinder is sometimes called the Elliptical Cylinder.

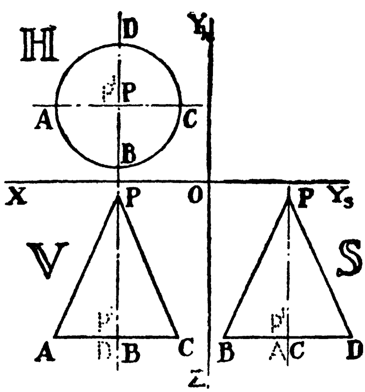


FIG. 51.

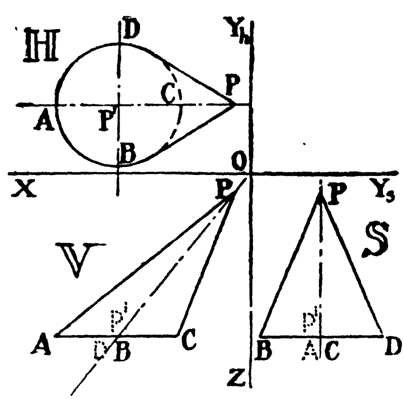


FIG. 52.

57. Straight and Inclined Circular Cones.—If a generating line *AP*, Fig. 48, meets an axis *PP'* at a point *P*, and is revolved about it, it will generate a Straight Circular Cone. The cone has both straight and circular elements, the circular elements increasing in size as they recede from the vertex *P*. The base *ABCD* is one of the elements. Fig. 48 unfolds to the form of Fig. 51.

The Inclined Circular Cone (Fig. 52) has straight and circular elements, but it is not generated by revolving a line about the axis. The circular elements move obliquely along the axis *PP'* and increase uniformly as they recede from the vertex *P*.

58. The Sphere.—The Sphere can be generated by revolving a semicircle about a diameter. Each point generates a circle, the radii of the circles for successive points having values varying between 0 and the radius of the sphere. Since the sphere can be generated by using any diameter as an axis, the number of ways in which the surface can be divided into circular elements is infinite.

59. Plotting of Cylinders and Cones and Spheres.—Cylinders and cones have often been considered by mathematicians as prisms and pyramids whose polygonal bases have become regular polygons of an infinite number of sides, *i.e.*, circles.

This being so it is not surprising that the *plotting of cylinders and cones* should follow the rules for plotting prisms and pyramids, as given on page 247 in Art. 39. These four steps are:

a. Plot the axis of the solid as a center line.

b. Draw the traces of the planes of the bases.

c. Draw the true shape of the base or bases on whichever plane of projection, $\mathbb{H}$, $\mathbb{V}$, $\mathbb{S}$ or $\mathbb{U}$, it properly appears. Letter points, on the model of Figs. 49 to 52, at the ends of the center lines of the bases.

d. Draw the lines representing curved edges. They are often lines joining ends of center lines of bases (AA', PA, etc.). If the axis of the solid is inclined some curved edges are likely to be lines tangent to a base circle or to two base circles. See the plan views in Figs. 50 and 52.

To plot a sphere is a simple task. Plot the center, C, in all views and with each projection of C as center describe a circle of the required diameter.

Problems V.

(For cross-section paper or blackboard.)

50. Make the descriptive drawing of a circle lying in a plane parallel to $\mathbb{S}$, center at C (3, 6, 7) and radius 5.

51. Make the descriptive drawing of a circle in a plane perpendicular to $\mathbb{H}$, whose trace on $\mathbb{H}$ passes through the points (12, 0, 0) and (0, 16, 0), with center at (6, 8, 10) and radius of 8. Plot in the order $\mathbb{H}$, $\mathbb{U}$, $\mathbb{V}$, $\mathbb{S}$, with $\mathbb{U}$ showing the true shape.

52. An ellipse lies in a plane, passing through the axis of Y, and making angles of 45° with $\mathbb{H}$ and $\mathbb{S}$. The $\mathbb{H}$ projection is a circle, center at (10, 10, 0) and radius 8. Plot $\mathbb{S}$ from $\mathbb{H}$ and $\mathbb{V}$. Prove that the projection on $\mathbb{V}$ is also a circle. Find the true shape of the ellipse by revolving it.

53. Construct a draftsman's ellipse on cross-section paper, with major axis 24 units, and minor axis 12 units. Perform the accurate plotting of the true ellipse on the same axes, one quadrant by the method of Fig. 42, one by that of Fig. 43, using 6 divisions for DE and OD. Note the serious error in the approximate ellipse in which $a = 2b$.

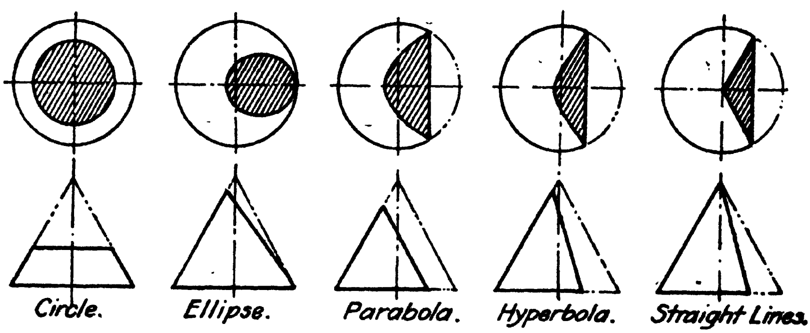
54. On coordinate paper, plot an ellipse by the method of Fig. 43, the major axis being 16 units long and the minor axis 8 units.

55. Connect the points A (10, 8, 10), B (8, 10, 6), C (6, 9, 4) and D (2, 2, 4) by a smooth curve, filling out poorly defined portions in $\mathbb{S}$ by extra points derived from $\mathbb{H}$ and $\mathbb{V}$.

CHAPTER VI.

INTERSECTIONS OF CURVED SURFACES, CYLINDERS, CONES AND SPHERES.

60. Elementary Intersections Must Be Studied First.—In Fig. 53 we have the complete series of intersections of a plane with a right circular cone. These are known as the "conic sections." Let us consider the simple cases first.



(A) (B) (C) (D) (E)

FIG. 53.

The first and last, marked (A) and (E), are the **elementary intersections.** They are elementary in two senses. They consist of a circle and two straight lines, the elementary lines which our drawing instruments so admirably and quickly produce. They are elementary, however, in a scientific sense. If the cone is considered to be created by the rotation of one straight line (the generating line) about an intersecting straight line (the axis), each *point* on the rotating line generates a circle, a *circular element* of the cone. The hatched circle in (A) is a *circular element,* and therefore an *elementary intersection.* The hatched triangle in (E) has as its base a line of intersection of the cutting plane with the base of the cone, and as sides, two *straight elements,* running down the sides of the cone. (B), (C), and (D) show the intersections of planes in-

clined at angles less than, equal to, and more than the angle of the inclined edge of the cone. They produce *higher plane intersections,* namely, the ellipse, parabola, and hyperbola.

The cylinder, created by revolving a straight line about a parallel straight line, has also circular elements, since any one point of the generating line creates a circle. It has straight elements, particular positions of the revolving line in its rotation.

A plane cuts a cylinder in three ways only, not five. (1) It may cut perpendicular to the axis, in which case we get a circle, an elementary intersection. (2) It may cut the axis at an angle creating an ellipse whose major axis may be of any size larger than the diameter of the cylinder and whose minor axis is equal to the diameter of the circle. This is a higher plane intersection. (3) The cutting plane may be parallel to or it may contain the axis. In either case it cuts the curved surface in two parallel straight lines, straight elements of the cylinder. It will also cut the cylinder's circular bases in straight lines and the whole intersection will be a rectangle.

An *inclined* circular cylinder differs in that the entire intersection of a plane parallel to or containing the axis is a parallelogram instead of a rectangle.

The elementary intersection of a plane, containing the vertex, with an *inclined* circular cone, is a triangle, usually not isosceles.

We have dwelt on these intersections of plane with cone and cylinder because the plane and cylinder are the most used shapes in machinery, and the cone, too, is not unusual. The designer thinks in terms of these surfaces, and the machine tools which build machinery create them.

Where a plane surface meets a curved surface, or two curved surfaces meet, there is a *line of intersection,* either a raised edge, sharp or rounded, or a V-shaped groove, or a groove rounded in by a "fillet."

Plane intersections are naturally the simplest, and we use the simplest class of them, the elementary intersections, as a tool to solve problems of higher plane intersections, and also problems of two curved surfaces intersecting in curved lines in space called *"space curves of intersection."*

For these harder problems you must keep clearly in mind the following elementary intersections:

1. A plane intersecting another plane cuts it in a *straight line.*
2. A plane intersecting a sphere cuts it in a *circle.*
3. A plane parallel to the axis of a cylinder cuts it in a *rectangle.*
4. A plane parallel to the base of a cylinder cuts it in a *circle.*
5. A plane containing the apex of a right or of an inclined cone cuts it in a *triangle.*
6. A plane parallel to the base of a cone cuts it in a *circle.*
7. A plane parallel to the axis of an inclined cylinder cuts it in a *parallelogram.*

61. Intersections of Curved Surfaces.—To solve one of these problems we must allow no preconceived ideas to divert us from a coldly logical system. We solve it, literally, point by point, by calling in a third surface, a plane, which must cut each of the given surfaces in simple elements.

Calling the surfaces A and B, and the new imaginary cutting plane C, we argue that *surface* A and *plane* C cut in a *line* of intersection, AC. That B and C cut in a *line* of intersection, BC. If AC and BC intersect in a *point* or *points,* such points, common to all three surfaces, must be on the *line* of intersection of A and B, the line AB desired.

The points produced by one cutting plane C are not enough to establish a line. A whole series of parallel planes must be used, each one as C in turn, and it is natural to number them 1, 2, 3, etc., and not to use the letter C.

How to choose the set of cutting planes will come next. Assuming a suitable plane to have been chosen, we have seven steps to take, as follows:

Pass plane No. 1 on that view where seen on edge, as a line or trace, in the region where A and B meet.

2. Draw the elementary intersection, A-1, on the other views of A.
3. Draw the elementary intersection, B-1, on the other views of B.
4. Where A-1 and B-1 meet mark the points, 1, clearly in pencil.
5. Pass a plane No. 2, adjacent to No. 1, and repeat the process.
6. Pass planes No. 3, No. 4, etc., until a large number of points have been found, enough to show clearly the extent and contour of the curve.
7. Pass a smooth curve through the points found.

Experience alone can show how many cutting planes may be needed in a given case. It depends on the regularity or irregularity (degree of contortion) of the curve, which itself can hardly be foreseen in advance.

Much of the difficulty encountered is in the proper selection of a system of cutting planes. Whatever surfaces you may have as given, each one can be cut by *at least two* systems of planes giving elementary intersections. The seven items in Art. 60 prove this.

If you cannot at once see a system of planes cutting elementary intersections with both of the given circles, go on to the next article.

62. Classification of the Ordinary Solutions.—To save time by preventing aimless search for a suitable cutting plane, the following six solutions may be tried in turn. In any case one is pretty sure to prove suitable. Often two, three or more are possible.

The first three make use of planes **parallel** to the planes of projection. They are:

Solution No. 1. Planes parallel to H.
Solution No. 2. Planes parallel to V.
Solution No. 3. Planes parallel to S.

This sequence is easily remembered. It is the same as that in which we usually enumerate the planes of projection, H, V and S. The typical cutting plane, of course, must cut both given surfaces in that region in which they intersect.

The second group of three makes use of planes **perpendicular** to H, V and S. They are:

Solution No. 4. Planes perpendicular to H.
Solution No. 5. Planes perpendicular to V.
Solution No. 6. Planes perpendicular to S.

These planes must also obey some geometrical condition such as "containing the axis," "parallel to the axis" or "containing the apex."

63. Critical Points.—After a solution has been chosen, a typical cutting plane clearly recorded, and points of intersection have been obtained from some adjacent planes, then, and only then, try the limiting cutting planes, and those which have some geometrical peculiarity. Those tangent to a curved surface, or containing an axis or center line, are apt to give "critical points," and are

often puzzling to the student, who is tempted to consider them too soon. Make it a rule to avoid them at first, and to pass planes close to them before finally passing the "critical planes." This approach by degrees is very instructive, as will be seen.

64. An Inclined Circular Cylinder Cut by an Inclined Plane.—In Fig. 54-A an inclined cylinder, axis *PP′*, is cut by a plane perpendicular to 𝕍, and inclined to ℍ. The traces of this plane are *IJ* in ℍ, *JK* in 𝕍, and *KL* in 𝕊.

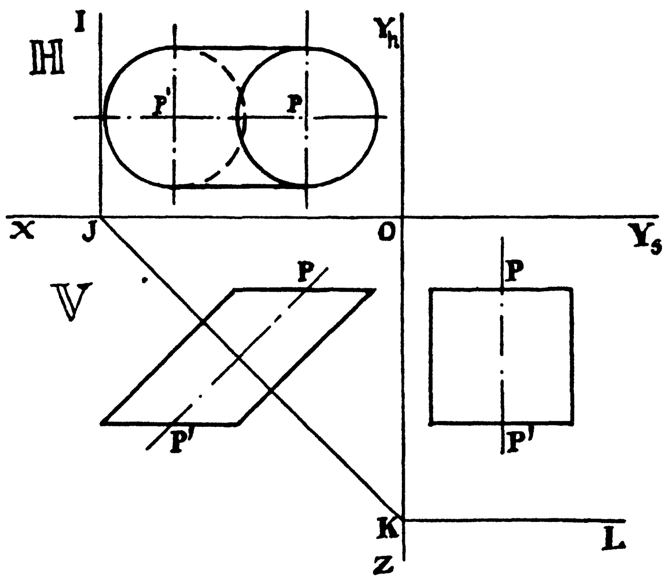


FIG. 54-A.

It is an Inclined Plane (see Art. 19), not an Oblique Plane. Having the descriptive drawing of the cylinder and the traces of the plane given, the problem is to draw the line of intersection of the surfaces. In this case the line of intersection is an ellipse, but the method of determining it permits the ellipse to be plotted whether it is recognized as such or not. No use is made of previous knowledge of the nature of the curve.

Solution No. 1. A plane parallel to ℍ, cutting the cylinder near the middle, will cut a circular element, and it will cut the plane, of course, in a straight line. Let us continue then.

In Fig. 54-B $T'T$ and TT'' are the traces of the cutting plane T. T cuts the axis PP' at p. Project p to 𝕳. On 𝕳 describe the circle btd, centered at p, the elementary intersection.

The cutting plane $T'T$ and the given plane JK are both perpendicular to 𝕍. They intersect in a line seen on end as the point j. Project j to 𝕳. jj' on 𝕳 is the line of intersection, seen as a line.

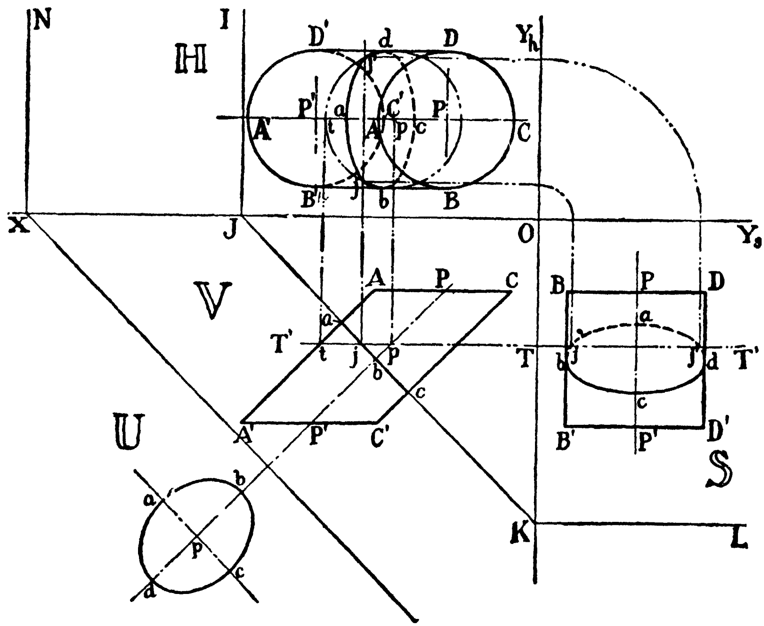


FIG. 54-B.

On 𝕳 the circle of intersection btd and the line of intersection jj' intersect at the points j and j'. These are the points of intersection of the lines of intersection and so are points on the line of intersection of the given surfaces. Project j and j' to 𝕾 also.

Other horizontal planes between a and c on 𝕍 give points analogous to j and j'. Find as many as are necessary for accuracy.

Critical planes are those through the points a, b and c on 𝕍. They give the ends of the major and minor axes of the ellipses.

At 𝖀 the true shape of the ellipse is seen. Since JK is perpendicular to PP' this ellipse is the "cross-section" of the cylinder.

Solution No. 2. In Fig. 54-C a plane, R, shown by its traces, $R'R$ on $\mathbb{H}$ and RR'' on $\mathbb{S}$, is the typical cutting plane.

R intersects the cylinder in a parallelogram, $ee'f'f$, as drawn on $\mathbb{V}$. To get this parallelogram e and f, where R cuts the top base, are located on $\mathbb{H}$, and projected to $\mathbb{V}$. On $\mathbb{V}$ ee' and ff' are drawn parallel to PP', or else e' and f' brought down from $\mathbb{H}$ and joined to e and f.

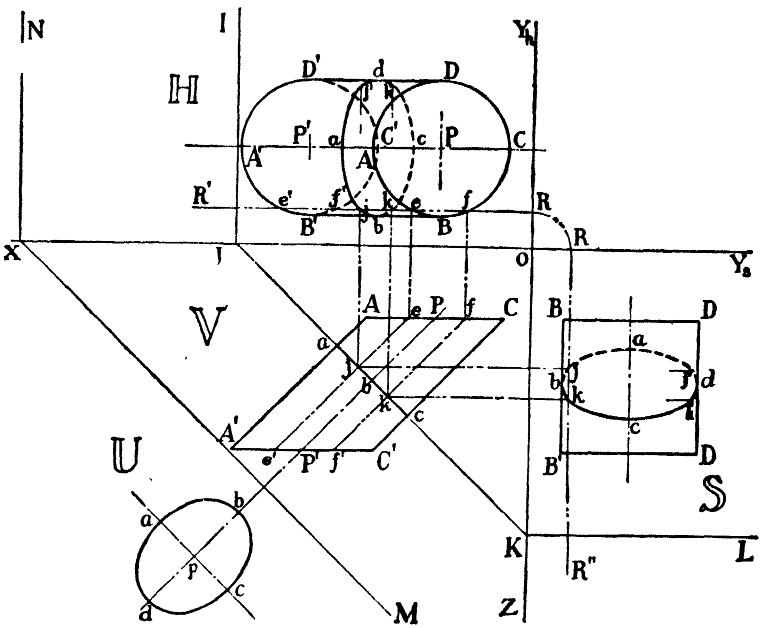


FIG. 54-C.

R intersects the given plane JK in a line which on $\mathbb{V}$ appears as JK itself. Therefore j and k, where ee' and ff' cut JK on $\mathbb{V}$, are the points of intersection of the lines of intersection of R with the two given surfaces. j and k, thus located on $\mathbb{V}$, are projected to the traces $R'R$ on $\mathbb{H}$ and RR'' on $\mathbb{S}$, to determine points on the ellipses there drawn.

Planes parallel to R, between BB' and DD' on $\mathbb{H}$, give further points on the ellipses until accuracy is attained.

Critical planes at BB', PP' and DD' give critical points, b, a, c and d, the ends of the major and minor axes of the ellipses.

65. A Cone Intersected by an Inclined Plane.—Fig. 55 shows the descriptive drawing of a right circular cone intersected by an inclined plane whose traces are JK and KL. Two methods of solution are shown.

Solution No. 1. The horizontal typical cutting plane T, traces $T'T$ and TT'', cuts the cone in a circle of diameter hh' as seen on $\mathbb{V}$. Describe this circle on $\mathbb{H}$, as $hfh'f'$. The planes T and JK,

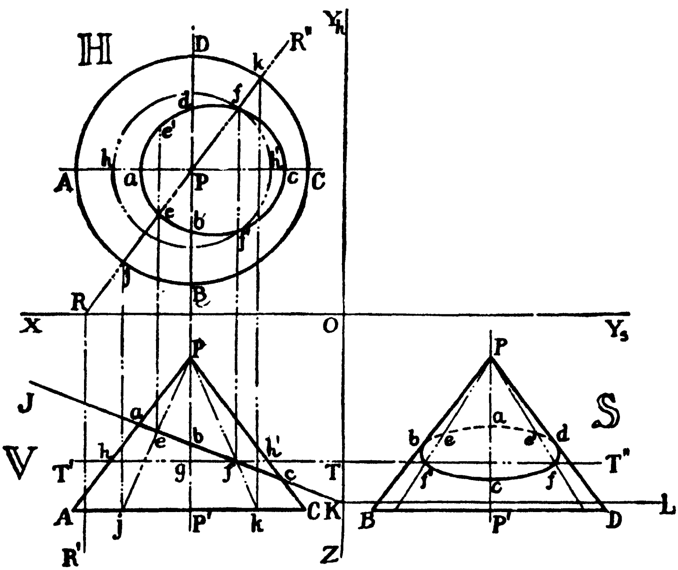


FIG. 55.

seen on edge on $\mathbb{V}$, intersect at f. f is a line seen on end on $\mathbb{V}$ but in $\mathbb{H}$ it appears as $f'f$. The intersections, $hfh'f'$ *and* ff' intersect at f and f', which are points on the elliptical curve of intersection. f and f' are squared out to $\mathbb{S}$, also, in the usual way by the third law of projection.

More planes passed between a and c on $\mathbb{V}$ will be required, and critical planes at a, b and c. That at b gives the points where the ellipse on $\mathbb{S}$ is tangent to the side elements of the cone, PB and PD.

Solution No. 4. A cutting plane, R, perpendicular to $\mathbb{H}$, and also containing the vertex, P, is shown in the Fig. 55, by its traces,

R'R and *RR"*. It cuts the circular base at *j* and *k* as seen on H. Project *j* and *k* to V and join *Pj* and *Pk*. These lines are seen to pierce the plane *JK* at *e* and *f*. These points, projected up to H, give two points on the curve of intersection there. *e* and *f* are located on S by squaring out or by first projecting *j* and *k* to S, joining *Pj* and *Pk* and projecting *e* from H to *Pj* and *f* from H to *Pk*.

More cutting planes are needed, all perpendicular to H, and all passing through *P* but at various angles. The critical planes are *APC* and *BPD*, giving points *a*, *b*, *c* and *d*.

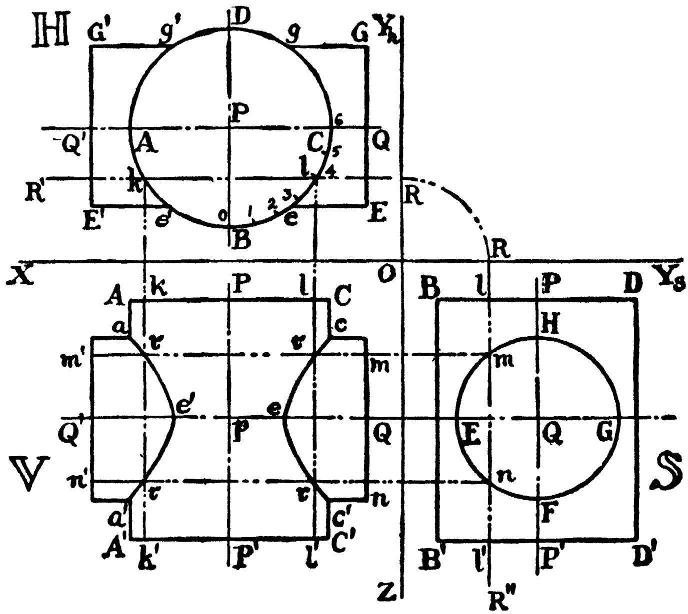


FIG. 56.

66. Intersection of Two Right Cylinders.—Two cylinders whose axes *PP'* and *QQ'* intersect at *p* are shown in Fig. 56.

Solution No. 2. The plane *R*, parallel to V, is shown by its traces, *R'R* on H and *RR"* and on S. This plane cuts the vertical cylinder, *PP'*, in a rectangle *kk'l'l*. *k* and *l* are located on H and projected to V, there locating the elements, *kk'* and *ll'*, on the curved surface of the cylinder. *R* cuts the horizontal cylinder in

a rectangle seen on edge on $\mathbb{S}$ but seen as the rectangle $mm'n'n$ on $\mathbb{V}$. The two rectangles intersect at four points, r, on $\mathbb{V}$. These points are on the line of intersection.

Parallel planes between EE' and QQ' on $\mathbb{H}$ give other points on the curve of intersection, as many as may be required. Critical planes at EE' and QQ' give the critical points e, e', a, a', c, and c'.

By symmetry we know the backs or the lines of intersection are directly behind the visible parts, and we stop at QQ'.

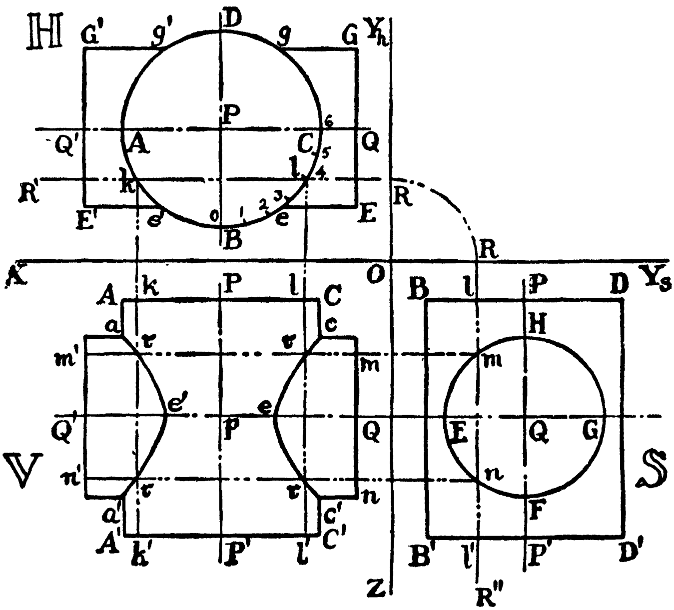


FIG. 56 (Repeated).

Fig. 56 has been drawn as if the actual solid were cut from one piece of material. Therefore on $\mathbb{V}$ there is no line from a to a'. There are no broken interior lines at all.

Solution No. 1 or Solution No. 3 would be as simple as No. 2.

If the axes do not intersect, as will result if QQ' is moved, parallel to itself, nearer to $\mathbb{V}$, a line of intersection of vastly different aspect is produced. The points a, a', c and c' on $\mathbb{V}$ are no longer points where lines of the same planes meet, despite their seeming intersection on $\mathbb{V}$, and are not points on the lines of intersection. There

will be two central critical planes, one containing PP', one QQ', and the back parts of the lines of intersection do not fall behind the visible parts. The passing of cutting planes must therefore be extended to the full width of the region of intersection.

67. Intersection of a Cylinder and a Sphere.—In Fig. 57-A, a sphere, centered at Q, is shown "pierced" by the cylinder PP'. Q is not on PP'.

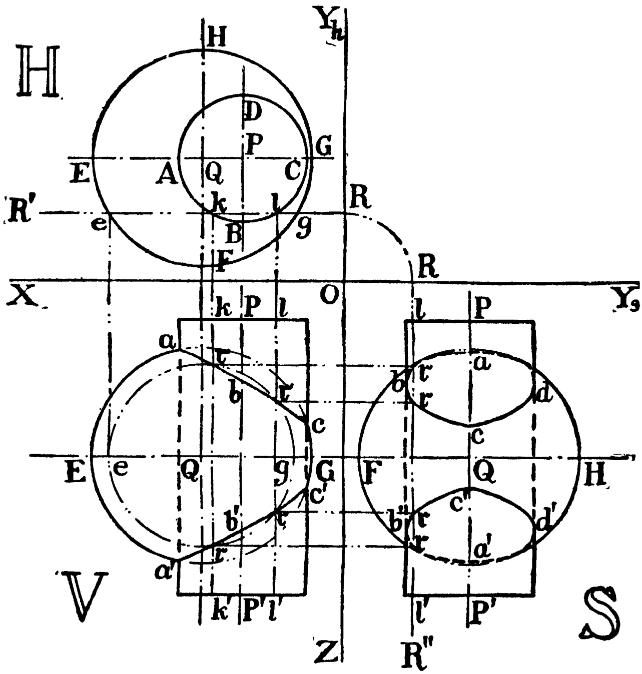


FIG. 57-A.

Solution No. 2. The typical cutting plane is R, traces $R'R$ on $\mathbb{H}$ and RR'' on $\mathbb{S}$. R intersects the cylinder in the rectangle $kk'l'l$ shown on $\mathbb{V}$, located by projection from k and l on $\mathbb{H}$. R intersects the sphere in a circle of diameter eg, as seen on $\mathbb{H}$. This circle described on $\mathbb{V}$, center at Q, intersects kk' and ll' at four points, r, located on $\mathbb{V}$ and later carried over to $\mathbb{S}$ as shown.

Critical planes are those through B, Q and D on $\mathbb{H}$ giving critical points a, b, c, d and a', b', c', d' on $\mathbb{V}$ and $\mathbb{S}$. d and d' are not

marked on $\mathbb{V}$. They lie behind b and b'.

Solutions No. 1 and No. 3 are also available.

Solution No. 3. This is shown on Fig. 57-B. One plane parallel to $\mathbb{S}$ is shown by its vertical traces, $S'S$ on $\mathbb{V}$ and SS'' on $\mathbb{H}$. The circular element it cuts with the sphere is drawn on $\mathbb{S}$ as a circle, its diameter having been found on either $\mathbb{H}$ or $\mathbb{V}$.

The rectangular intersection of the plane with the cylinder is shown on $\mathbb{S}$. The straight elements were located on $\mathbb{H}$ and projected to $\mathbb{S}$.

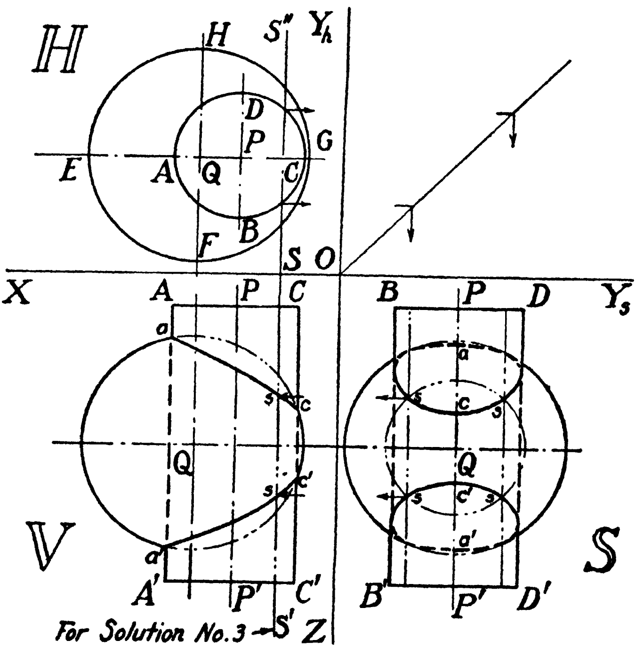


FIG. 57-B.

Four points of intersection, s, on $\mathbb{S}$ project to two on $\mathbb{V}$.

Several other cutting planes are wanted, of course. Critical planes are those through c, P, Q, and a. They give twelve points on $\mathbb{S}$, eight of which are points of tangency.

Solution No. 1. A horizontal plane, whose traces are like $T'T$ and TT'' of so many of our previous examples, will give a circular intersection with the sphere on $\mathbb{H}$ and also a circular intersection with the cylinder, coinciding on $\mathbb{H}$ with the circle $ABCD$. Points

of intersection are found on $\mathbb{H}$ and projected to $\mathbb{V}$ and $\mathbb{S}$. The horizontal planes must be between *a* and *c*.

68. Intersection of a Cone and a Cylinder with Axes Parallel.—This problem is shown in Figs. 58-A and 58-B in which the vertical cylinder, QQ', pierces the vertical cone PP'.

Solution No. 1. The plane T, parallel to $\mathbb{H}$, with trace $T'T$ on $\mathbb{V}$ and TT'' on $\mathbb{S}$, cuts the cone in a circle, diameter mm' as

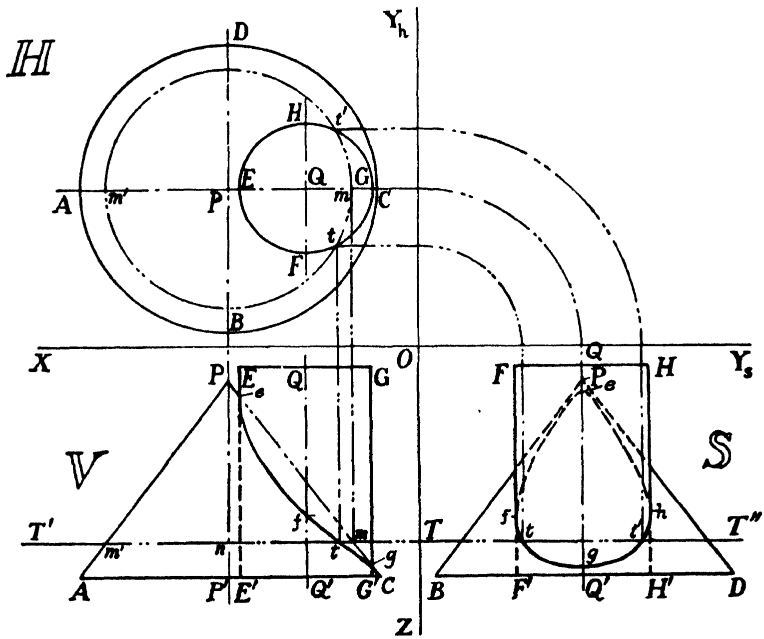


FIG. 58-A.

seen on $\mathbb{V}$. Draw this circle mtm' on $\mathbb{H}$. T cuts the cylinder in a circle of the same size as the top base and identical on $\mathbb{H}$ with the circle $EFGH$. The two points, t, on $\mathbb{H}$ are points on the line of intersection and project to $\mathbb{V}$ and $\mathbb{S}$, to the plane T, to give the points on the curve of intersection shown there.

Many more horizontal planes must be passed between g and e to give the curve with certainty. Critical planes at g and e give those points themselves. f and h, points of tangency, on $\mathbb{S}$, are projected from f (on $\mathbb{V}$), the point of intersection of the curve with the element FF' which on $\mathbb{V}$ overlies QQ'.

Solution No. 4. A plane *R*, perpendicular to ℍ, and containing the axis of the cone, as shown on Fig. 58-B, cuts a straight element, *Pr*, down the side of the cone where the cylinder, *QQ′*, pierces it. Locate *r*, where *R* cuts the base of the cone, on ℍ, and project *r* to 𝕍 and 𝕊. Connect *P* to *r* in each of those views.

R cuts the curved surface of the cylinder in two straight elements, their top points *w* and *s* being easily located on ℍ. Project *w* and *s* to 𝕍 and 𝕊 and draw the elements *ww′* and *ss′* (*ww′* on 𝕍

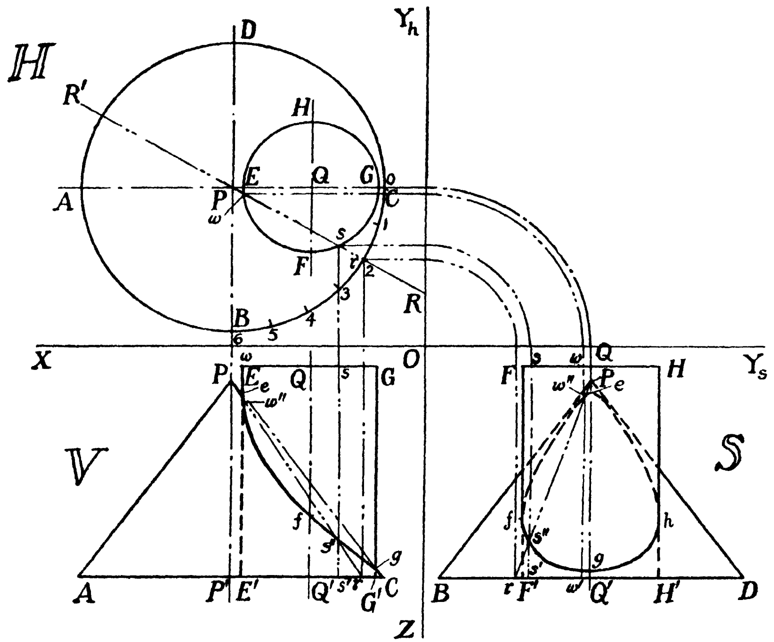


FIG. 58-B.

is not distinguishable from *EE′*). *Pr* intersects *ww′* at *w″* and *ss′* at *s″*. The plane *PC* gives the critical points *e* and *g*.

In practice a set of planes through *P* on ℍ, making equal angles, would probably be used. The small numbers, 0 to 6, at intervals of 15°, are quite suitable places.

69. Intersection of a Cylinder and a Cone, with Axes Meeting.— Figs. 59-A and 59-B show this case, drawn with the cylinder, *QQ′*, piercing the cone, *PP′*.

Solution No. 1. Fig. 59-A shows the plane T, traces $T'T$ on V and TT'' on S, cutting the cone in a circle of diameter mn, seen on V as a straight line.

Project m to H and, with P as center and Pm as radius, draw the circle $mttn$. This is the circle seen in its true shape.

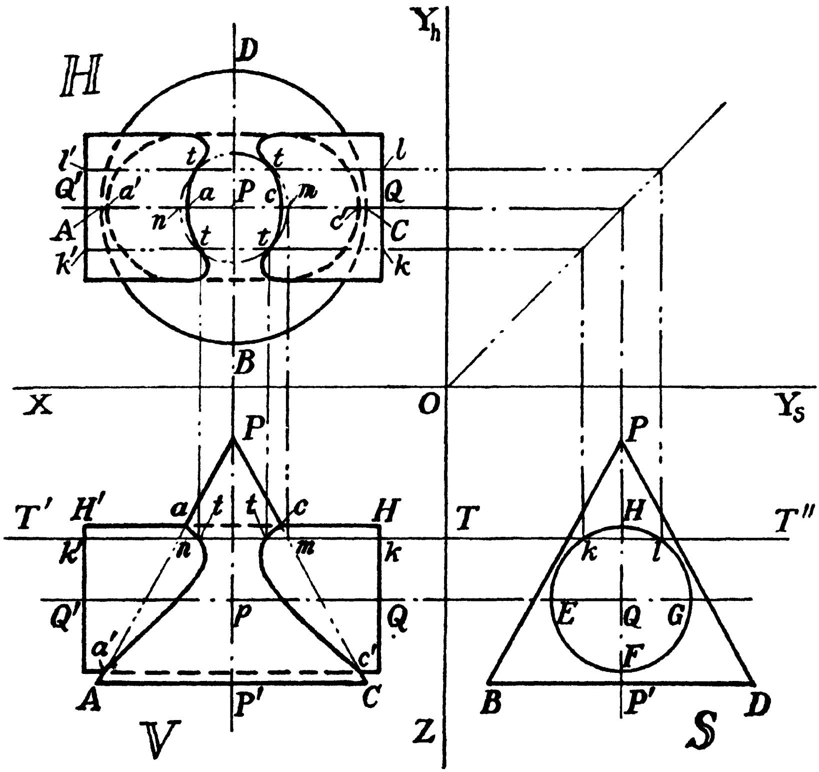


FIG. 59-A.

The plane T cuts the cylinder in a rectangle $kk'l'l$. The points k and l are determined on S and projected to H where the rectangle appears as a rectangle. The circular intersection of T with the cone and the rectangular intersection of T with the cylinder are seen to cut each other at four points, t, on H. Project these points down to give two points on V.

Eight or ten horizontal planes should be used to give points enough to determine the curves of intersection with certainty.

Three critical planes are needed. One tangent to HH', the top element of the cylinder, will give c and a as critical points. One tangent to the cylinder at the bottom element, FF', will give the points c' and a'.

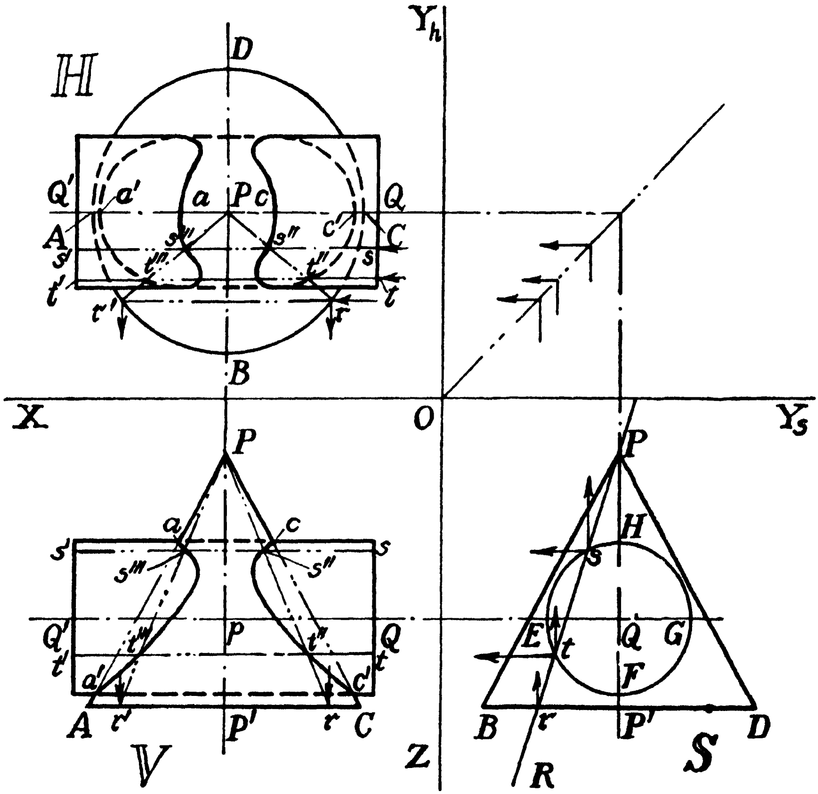


FIG. 59-B.

A plane at QQ' on $\mathbb{V}$ gives critical points on $\mathbb{H}$, at which the curves of intersection are tangent to the side elements of the cylinder. At these points full lines change to broken lines, for both of the curves of intersection and both of the side elements.

Solution No. 6. Fig. 59-B shows the solution by planes perpendicular to $\mathbb{S}$, through the vertex P. There is a rectangle, $ss't't$, representing the intersection of plane P with cylinder QQ', and a

triangle, Prr', representing the intersection of R with the cone PP'. Both show clearly on $\mathbb{H}$ and $\mathbb{V}$, and they intersect each other at points s'', s''', t'' and t'''. The arrows show how points are projected from view to view in executing the work.

Problems VI.

56. Draw the projections of a cylinder, whose axis is P (6, 2, 6), P' (6, 16, 6), and radius 5. Draw the intersection of this cylinder with a plane parallel to $\mathbb{H}$, at 4 units from $\mathbb{H}$, and with a plane parallel to $\mathbb{V}$, at 10 units from $\mathbb{V}$.

57. An inclined circular cylinder has its bases parallel to $\mathbb{S}$. Its axis is P (2, 7, 7), P' (14, 7, 13). Its radius is 5. Draw the $\mathbb{V}$ and $\mathbb{S}$ projections and the intersection with a plane parallel to $\mathbb{S}$, at 6 units from $\mathbb{S}$, and with a plane parallel to $\mathbb{V}$, at 3 units from $\mathbb{V}$.

58. Draw a cone with vertex, P (4, 8, 8), center of base, P' (16, 8, 8), and radius 6. The base is parallel to $\mathbb{S}$. Draw the intersection with a plane parallel to $\mathbb{S}$, 12 units from $\mathbb{S}$, and with a plane perpendicular to $\mathbb{S}$, its trace through (0, 8, 8) and (0, 14, 0).

59. A cone has an axis P (8, 2, 2), P' (8, 14, 10). Its base is in a plane parallel to $\mathbb{V}$, 14 units from $\mathbb{V}$, and its radius is 6 units. Draw the intersection with a plane perpendicular to $\mathbb{S}$, containing the vertex and the point (0, 14, 12).

60. A sphere has its center at (8, 8, 8), radius 5 units. Draw the "elementary" intersections with a cylinder whose axis is P (8, 8, 0), P' (8, 8, 16), radius 4 units, bases parallel to $\mathbb{H}$.

61. A sphere has its center at (8, 8, 8) and a radius of 5 units. Find its "elementary" intersections with a cone whose vertex is P (0, 8, 8), base parallel to $\mathbb{S}$, radius 6 units, center at P' (16, 8, 8).

62. An inclined cylinder has one base in $\mathbb{H}$ and one in a plane parallel to $\mathbb{H}$. Its axis is P (11, 8, 0), P' (5, 8, 16). Its radius is 4 units. It is cut by a plane perpendicular to $\mathbb{V}$, whose trace passes through the points (5, 0, 0) and (11, 0, 16). Draw the three views and show the solution used and its number.

63. A cone has its vertex in $\mathbb{H}$ at (6, 6, 0) and its base parallel to $\mathbb{H}$, center at (6, 6, 12), radius 5. It is intersected by a plane containing the axis of Y and making 45° angles with $\mathbb{H}$ and $\mathbb{S}$. Draw the projections. Show solution used and its number.

64. A cone has its vertex at (2, 14, 16) and its base a circle in $\mathbb{H}$, center (8, 8, 0), radius 6. Find its intersection with a plane parallel to $\mathbb{S}$, 4 units from $\mathbb{S}$. Mark the solution used, by number.

65. A right circular cylinder has its base in $\mathbb{S}$, center at (0, 8, 8), radius 4. Its axis is 16 units long. Another right cylinder has its base in $\mathbb{H}$, center at (8, 8, 0) radius 5, axis 16 units long. The smaller pierces the larger. Draw their line of intersection.

66. A right circular cylinder has its base in $\mathbb{S}$, center at (0, 7, 8), radius 4, axis 16 units long. Another right circular cylinder has its base in $\mathbb{H}$, center (8, 9, 0), radius 5, axis 16 units long. The smaller cylinder pierces the larger. Draw their line of intersection.

67. Two inclined circular cylinders, of 3 units radius, have their bases in $\mathbb{H}$ and $\mathbb{H}'$, 16 units from $\mathbb{H}$. The axis of one is P (4, 8, 0), P' (12, 8, 16), and that of the other is Q (12, 8, 0), Q' (4, 8, 16). Prove that their intersection is in two parts, one a circle parallel to $\mathbb{H}$, one an ellipse, parallel to $\mathbb{S}$.

68. A sphere has its center at (8, 9, 8) and radius 6½ units. A vertical right circular cylinder has its top base in $\mathbb{H}$, center at (8, 6, 0), radius 4, length 16 units. Find the intersection.

69. A right circular cylinder, axis P (0, 8, 9), P' (16, 8, 9), radius 5, is pierced by a right circular cone. The base of the cone is parallel to $\mathbb{H}$, center at Q' (8, 8, 16), radius 6. Its vertex is Q (8, 8, 0). Find the line of intersection.

70. An inclined cylinder has an oblique axis, P (0, 11, 5), P' (16, 5, 11). The radius of the circular base is 4 units. One base is in $\mathbb{S}$ and the other in $\mathbb{S}'$, parallel to $\mathbb{S}$, 16 units away. The cylinder is cut by a plane parallel to $\mathbb{V}$ at 7 units from $\mathbb{V}$. Draw the cylinder and the line of intersection.

71. An inclined cylinder has an oblique axis, P (0, 11, 5), P' (16, 5, 11). One base is in $\mathbb{S}$ and one in $\mathbb{S}'$, 16 units from $\mathbb{S}$. The bases are circles of 4 units radius. This cylinder is cut by a plane perpendicular to $\mathbb{V}$, its trace passing through the points (2, 0, 0) and (14, 0, 16). Draw the three views.

Sheets 9 to 12, as described on pages 368 to 371, are designed to be executed at this place in the study of the subject.

CHAPTER VII.

SURFACES OF REVOLUTION.

70. Surfaces of Revolution.—In general, any line, straight or curved, may be revolved about an axis, thus creating a *surface of revolution.* Every point on the "generating line" creates a "cir-

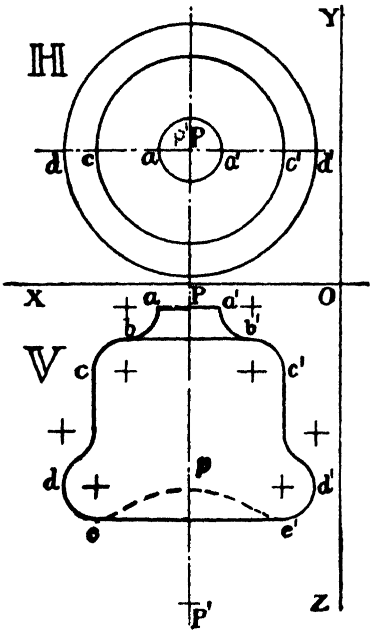


FIG. 60.

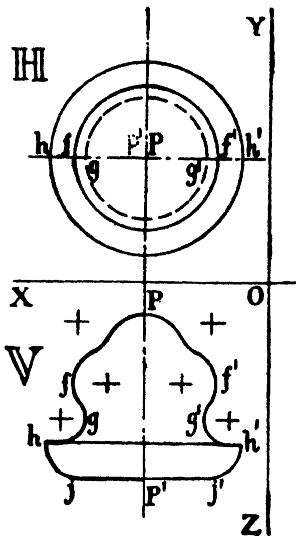


FIG. 61.

cular element" of the surface, and the plane of each circular element is perpendicular to the axis of the surface.

In Fig. 60 *Pabcdep* is the generating line and *PP′* the axis. *Pa′b′c′d′e′p* is another position of the generating line after rotating 180°. In Fig. 61 *PfghjP′* is the initial position of the generating line, *Pf′g′h′j′P′* another position, and *PP′* is the axis.

The straight circular cylinder is a simple case of the general class of surfaces of revolution. The cone and the sphere are also surfaces of revolution, as they are generated by revolving a line about an axis. A plane also may be generated by revolving a straight line about a perpendicular line as an axis.

If a circle be revolved about an axis in its own plane, but entirely exterior to the circle, a solid, called an "anchor ring," is generated. A small portion of this surface, part of its inner surface, is often spoken of as a "bell-shaped surface," from its similarity to the flaring edge of a bell.

These are shown in Figs. 62 and 63. Note that the *solid* of Fig. 63 is not part of a solid similar to Fig. 62, but would fit against it in such a place as $fgg'f'$.

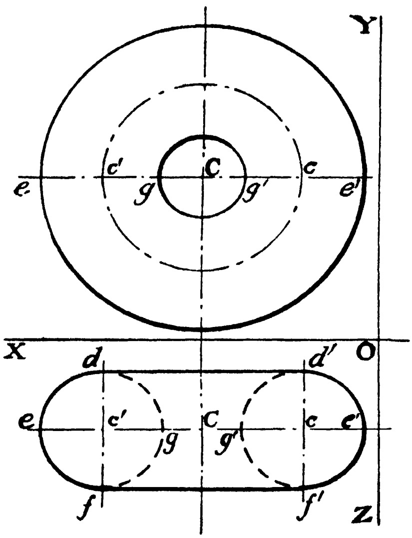


FIG. 62.

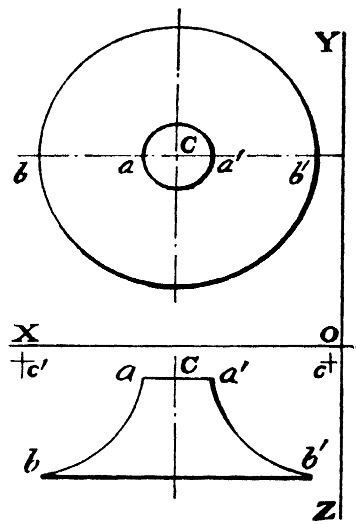


FIG. 63.

Any angular point on the generating line, as *a* (Fig. 63), creates a circular edge on the surface. This ridge appears as a circle on H and a line equal in length to the diameter on V. *b* creates another such ridge.

However, curved surfaces bring into play the Principle of Tangent Projectors, described in Art. 55, p. 265, and surfaces of revolution are no exception. In drawing them we find some circular elements which appear on one projection only. For example, any portion of a generating line which is perpendicular to the axis, as *d* (Fig. 62), even if for an infinitely short distance only, creates a line on V as dd', but no corresponding circle on H. Also, any point, as *e* (Fig. 62), where the generating line is parallel to the

axis (for a finite or an infinitesimal distance), generates a circular element on 𝕳 but no corresponding straight line on 𝖁.

Of course surfaces of revolution are not always drawn with axis, PP' vertical. All that is said above about the 𝕳 projection refers, in the general case, to that view in which the axis is seen on end (the "end view") and all that is said about the 𝖁 projection refers to that plane of projection (the "side view") which is parallel to the axis of revolution.

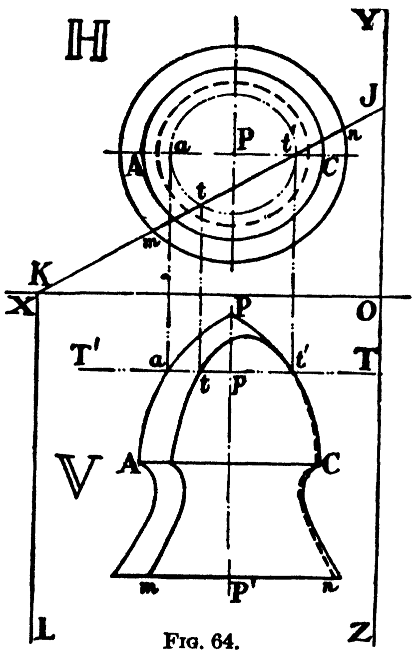


FIG. 64.

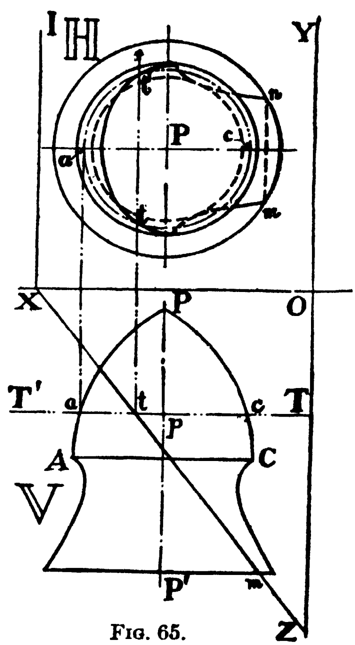


FIG. 65.

71. Intersection of a surface of Revolution and an Inclined Plane.—In Figs. 64 and 65 a surface of revolution is shown. It is cut by an inclined plane perpendicular to 𝕳 in the first case, and by one perpendicular to 𝖁 in the second case. The planes are given by their traces, and the problem is to find the curves of intersection. Both solutions make use of cutting planes perpendicular to PP', the axis of revolution of the curved surface.

For problems involving surfaces of revolution always try first planes perpendicular to the axis of revolution.

In Fig. 64 a plane T, taken at will perpendicular to PP', cuts the surface of revolution in a circular element seen as the straight line at' in $\mathbb{V}$. a is projected to $\mathbb{H}$ and the circle att' drawn. The inclined plane whose traces are JK and KL is intersected by the plane T in a line whose horizontal projection is the line JK itself. t and t' (on $\mathbb{H}$) are therefore the intersections of the intersections and are projected to the front elevation, giving points on the required line of intersection. A system of planes such as T defines points enough to fully determine the curve, $mtt'n$.

In Fig. 65 the given plane has the traces IX and XZ. The plane T intersects the surface of revolution on the circle $atct'$, and it

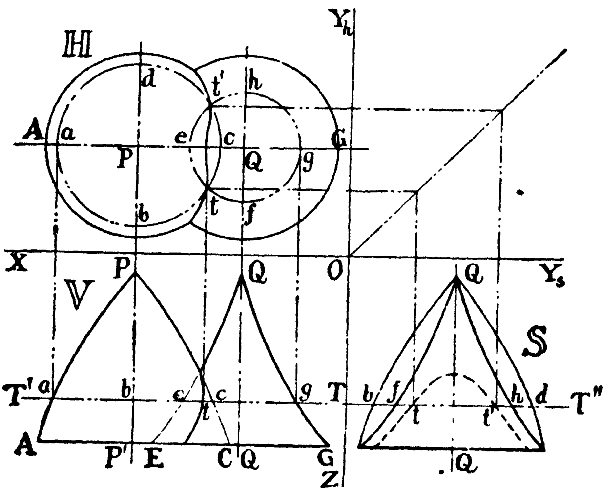


FIG. 66.

intersects the plane in the line tt', seen on end in $\mathbb{V}$ as the point t. t and t' in $\mathbb{H}$ are points on the required curve of intersection, $mtt'n$.

The point of this surface of revolution APC has been given a special name. It is an "ogival point." The generating line AP is an arc of 60°, center at C, and conversely the generating line PC has its center at A. The shell used in ordnance is usually a long cylinder with an ogival point. A double ogival surface is produced by revolving an arc of 120° about its chord.

72. Intersection of Two Surfaces of Revolution: Axes Parallel.—This problem is illustrated in Fig. 66, where two surfaces of

revolution are shown. A horizontal plane T cuts both surfaces in circular elements. These elements are drawn in ℍ as circles *abcd* and *efgh*. t and t' are the intersections of the intersections. From ℍ t and t' are projected to 𝕍 and 𝕊. The problem in Art. 73 is but a special case of this general problem. In addition to the solution by horizontal planes another solution is there possible, due to special properties of the cone and cylinder.

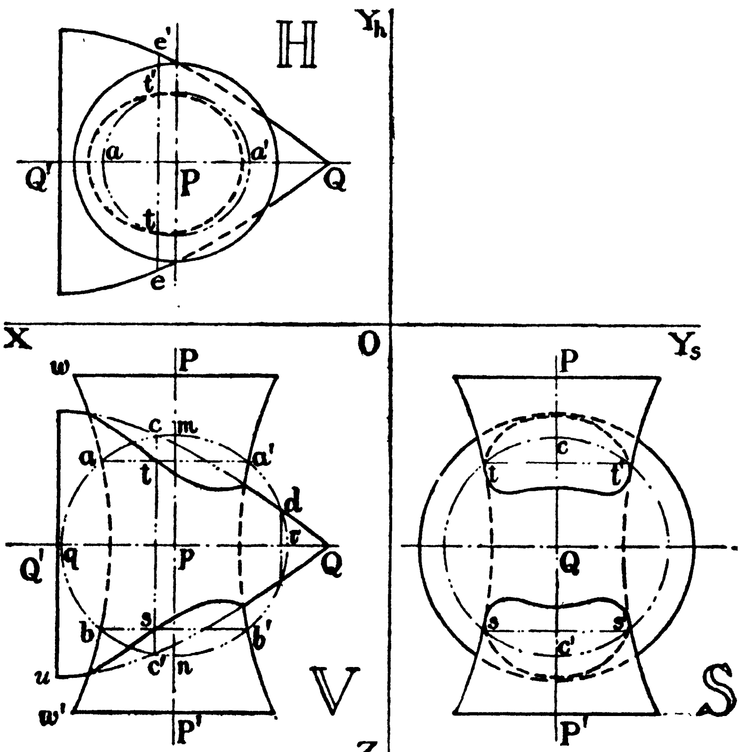


FIG. 67.

73. Intersection of Two Surfaces of Revolution: Axes Intersecting.—An example of two surfaces of revolution whose axes intersect is given by Fig. 67. A surface is formed by the revolution of the curve ww' about the vertical axis PP', and another surface by revolving the curve uQ about the horizontal axis QQ'. The in-

tersection of the axes PP' and QQ' is the point p. The peculiarity of this case is that no plane can cut both surfaces in circular elements. However, a sphere described with the point of intersection of the axes as a center, if of proper size, will intersect both surfaces in circular elements. **V** is parallel to both axes and on this projection a circle is described with p as center representing a sphere. The radius is chosen at will. To keep the drawing clear, this sphere *has not been described on plan or side elevation,* as it would be quite superfluous in those views.

The sphere has the peculiarity that it is a surface of revolution, using any diameter as an axis. The curve ww' and the semicircle *mabn* are in the same plane with the axis PP' When both curves are revolved about PP', a and b, their points of intersection, generate circular elements common to the sphere and to the vertical surface PP'. These circles are "seen on edge" on **V** as straight lines aa' and bb', of equal length in this particular case. Draw the **H** projection of these circles next, by projecting a up and describing the circle $at'a't$. Project horizontally to **S** to draw two straight lines across the surface PP', equal to aa' and bb' in length. They represent the circles seen on edge on **S**. (t, t', s and s' are not at the ends of these lines but are close to them.)

Note that the curve uQ, on **V**, the semicircle *rnq* and the axis QQ' are all in the same plane. The curves intersect at c', and when they are revolved about QQ', c' generates a circle, parallel to **S**, which appears on **V** at the straight line $c'c$. This circle appears as a true circle on **S**, center at Q, diameter $c'c$. It appears on **H** as a diameter ee', equal in length to cc'. A second circle of intersection of sphere and surface QQ', at d (on **V**) is ignored because distant from the surface PP'.

We have now drawn the intersections of the sphere with both surfaces of revolution and we identify the *intersections of the intersections* as t and t' on **H**, t and s on **V** and t, t', s and s' on **S**.

For the complete solution, a number of auxiliary spheres, differing slightly in radius, must be used.

74. Complete List of Solutions.—In addition to the six usual solutions, listed in Art. 62 of p. 274, we now have the solution by spheres, as just described, for *Solution No. 7.* We shall have, also, on p. 340, a *Solution No. 8,* by planes perpendicular to **U**, as our final method.

The complete list of solutions of the problem of intersecting curved surfaces is then:

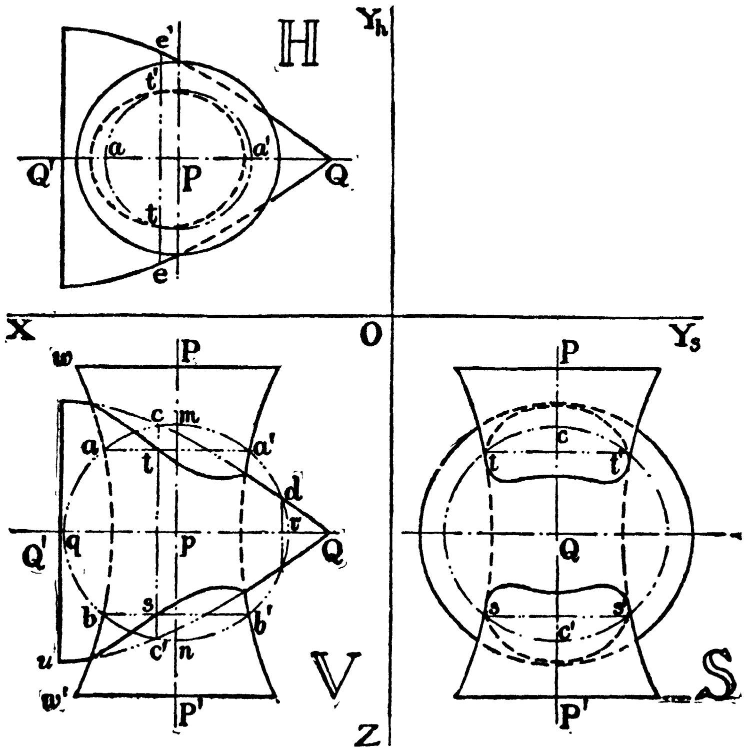


FIG. 67—Repeated.

Solution No. 1. Planes parallel to H.
Solution No. 2. Planes parallel to V.
Solution No. 3. Planes parallel to S.
Solution No. 4. Planes perpendicular to H.
Solution No. 5. Planes perpendicular to V.
Solution No. 6. Planes perpendicular to S.

Nos. 4, 5 and 6 must also obey some geometrical conditions such as "containing the axis," "parallel to the axis" or "containing the vertex."

Solution No. 7. Spheres whose centers are the point of intersection of two axes of revolution.

Solution No. 8. Planes perpendicular to U.

Problems VII.

72. A surface of revolution is formed by revolving a circle whose center is at (12, 8, 8) and radius 3 units, lying in a plane parallel to $\mathbb{V}$, about an axis perpendicular to $\mathbb{H}$ at the point (8, 8, 0). It is cut by a plane parallel to $\mathbb{H}$ at a distance of 6 units from $\mathbb{H}$. Draw the intersection. It is an "elementary intersection."

73. In Fig. 60 let the generating line *Pabcde* be revolved about ee' as an axis. Assume any reasonable dimensions for the line and draw the $\mathbb{V}$ and $\mathbb{S}$ projections of the surface of revolution thus formed. Draw the "elementary" intersection with a plane parallel to $\mathbb{S}$ just to the right of *d*.

74. In Fig. 61 let the generating line *Pfgh* be revolved about hh' as an axis. Assume any dimensions for the line and draw the $\mathbb{V}$ and $\mathbb{S}$ projections of the surface of revolution formed.

75. An anchor-ring is formed by revolving a circle of 6 units diameter about a vertical axis, so that its center moves in a circle of 10 units diameter, center at *Q* (8, 8, 8). The anchor-ring is intersected by a plane parallel to $\mathbb{V}$ passed through the point *A* (8, 6, 8). Draw the projections of the ring, the traces of the plane and the line of intersection.

76. The same anchor-ring is intersected by a plane perpendicular to $\mathbb{V}$, having a trace passing through the points *C* (0, 0, 2) and *D* (8, 0, 8). Make the descriptive drawing and show the true shape of the lines of intersection.

77. The same anchor-ring is intersected by a right circular cylinder, axis *P* (12, 8, 0), P' (12, 8, 16), and diameter 4 units. Make the descriptive drawing of the anchor-ring, imagining it to be pierced by the cylinder.

78. An anchor-ring has an axis *P* (0, 8, 8), P' (16, 8, 8). Its center moves in a plane 7 units from $\mathbb{S}$, describing a circle of 8 units diameter. The radius of the describing circle is 3 units. It is intersected by an ogival point whose axis is a vertical line *Q* (7, 8, $3\frac{7}{8}$), Q' (7, 8, 16). The generating line of the ogival point is an arc of 60°, with center at (0, 8, 16), and radius 14 units. The point *Q* is the vertex and the point Q' is the center of the circular base of 7 units radius. The axes intersect at *p* (7, 8, 8).

Draw the projections and the line of intersection, front and side elevations only.

79. The line P (4, 13, 8), P' (16, 8, 8) is the chord of an arc of 90°, whose radius is 9.2 units. The arc is the generating line of a surface of revolution of which PP' is the axis. Draw the projection on $\mathbb{H}$. Draw the end view on an auxiliary plane $\mathbb{U}$ perpendicular to PP', the trace of $\mathbb{U}$ on $\mathbb{H}$ intersecting OX at (16, 0, 0). The surface is intersected by a plane perpendicular to $\mathbb{H}$ and containing the line PP'. Draw the line of intersection on $\mathbb{V}$.

80. The same surface is intersected by a plane perpendicular to $\mathbb{H}$ whose trace in $\mathbb{H}$ passes through the points (4, 16, 0) and (16, 5, 0). Draw the line of intersection on $\mathbb{V}$.

81. The line P (3, 8, 8), P' (13, 8, 8) is the chord of an arc of 90°, radius 7.07 units. It is the axis of revolution of a surface of which the arc is the generating line. It is intersected by a right circular cone having its vertex at Q (8, 8, 2), and center of base at Q' (8, 8, 12), radius of base 5 units. Draw the line of intersection.

Sheets 13 to 16, described on pages 372 to 377, are designed to be executed at this place in the study of the subject.

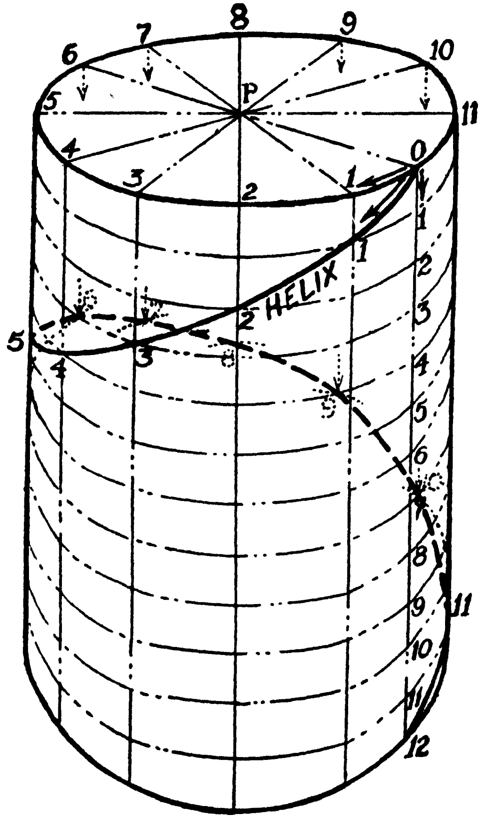


FIG. 68-A.

CHAPTER VIII.

THE HELIX AND THE HELICOIDAL SURFACES.

75. The Helix.—The curve *in space* (not a plane curve) which is most commonly used in machinery, is the helix. This curve is described by a point revolving uniformly about an axis and at the same time moving uniformly in the direction of that axis. It is popularly called a "cork-screw" curve, or "screw thread," or even, quite incorrectly, a "spiral." Fig. 68-A, opposite, is a perspective view.

The helix lies entirely on the surface of a cylinder, the radius of the cylinder being the distance of the point from axis of rotation, and the axis of the cylinder the given direction.

Fig. 68-A represents a cylinder on the surface of which a moving point has described a helix. Starting at the top of the cylinder, at the point marked 0, the point has moved uniformly completely around the cylinder at the same time that it has moved the length of the cylinder at a uniform rate. The circumference of the top circle of the cylinder has been divided into twelve equal parts by radii at angles of 30°, the apparent inequality of the angles being due to the perspective of the drawing. The points of division are marked from 0 to 11, point 12 not being numbered, as it coincides with point 0. The length of the cylinder is divided into twelve equal parts on the vertical line showing the numbers from 0 to 12, and at each point of division a circle, parallel to the top base, is described about the cylinder. The helix is the curve shown by a heavy line. From point 0, which is the zero point of both movements, the first twelfth part of the motion carries the point from 0 to 1 around the circumference, and from 0 to 1 axially downward, at the same time. The true movement is diagonally across the curved rectangle to the point marked 1 on the helix. This movement is continued step by step to the points 2, 3, etc. In the position chosen in Fig. 68-A, points 0, 1, 2, 3, 4, 12 are in full view, points 5 and 11 are on the extreme edges, and the intermediate

points (from 6 to 10) are on the far side of the cylinder. The construction lines for these latter points have been omitted, in order to keep the figure clear.

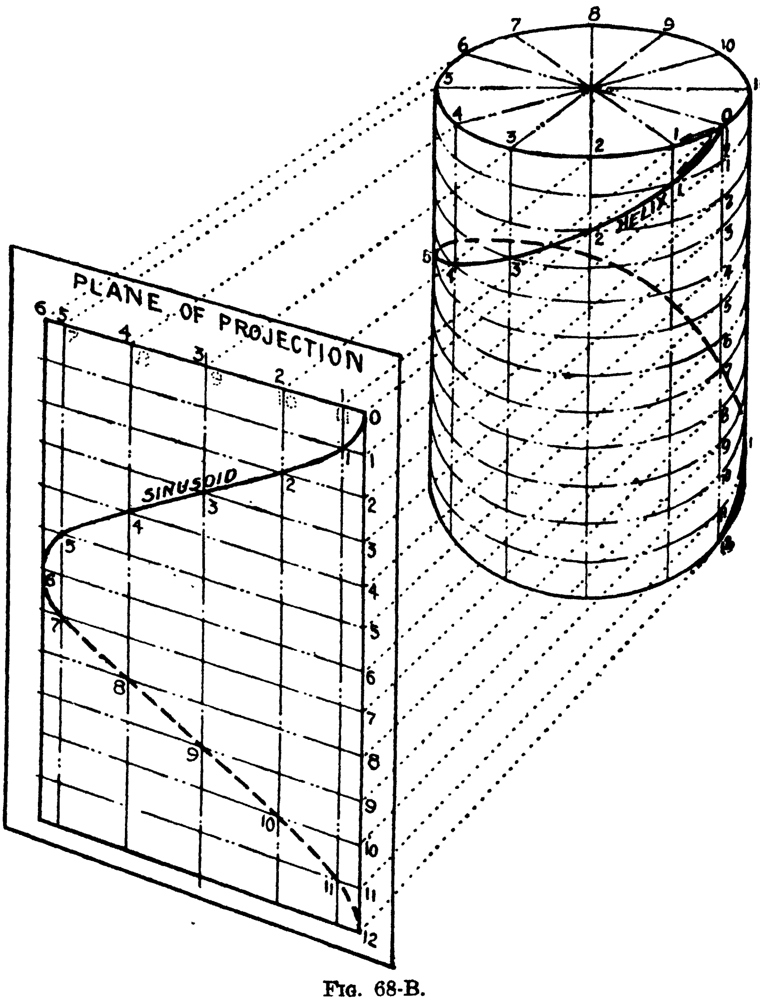


FIG. 68-B.

76. Projections of the Helix.—The projection of this curve on a plane parallel to the axis of the cylinder is shown in Fig. 68-B. The circles described about the cylinder become equidistant parallel

straight lines. The axial lines remain straight but are no longer equally spaced, and the curve is a kind of continuous diagonal to the small rectangles formed by these lines on the plane of projection.

The projection of the helix on any plane *perpendicular* to the axis of the cylinder is a circle coinciding with the projection of the cylinder itself. The top base is such a plane and on it the projection of the helix coincides with the circumference of the base.

77. Descriptive Drawing of the Helix.—The typical descriptive drawing of a helix is shown in Fig. 69-A. The axis of the cylinder is perpendicular to $\mathbb{H}$, and the top base is parallel to $\mathbb{H}$. The helix in $\mathbb{H}$ appears as a circle. In $\mathbb{V}$ it appears as on the plane of projection in Fig. 68-B, but this view is no longer seen obliquely as is there represented.

This $\mathbb{V}$ projection of the helix is a plane curve of such importance as to receive a separate name. It is called the "sinusoid." Since the motion of the describing point is not limited to one complete revolution, it may continue indefinitely. The part drawn is one complete portion and any addition is but the repetition of the same moved along the axial length of the curve. The proportions of the curve may vary between wide limits depending on the relative size of the radius of the cylinder to the axial movement for one revolution. This axial distance is known as the "pitch" of the helix. It is the distance the common screw advances in one complete turn.

In Fig. 69-A the pitch is about three times the radius of the helix. In Fig. 69-B, a short-pitch helix is represented, the pitch being about $\frac{3}{4}$ the radius, and a number of complete rotations being shown.

The proportions of the helix depend therefore on the radius and on the pitch. To execute a drawing, such as Fig. 69-A, describe first the view of the helix which is a circle. Divide the circumference into any number of equal parts (12 or 24 usually). From these points of division project lines to the other view or views. Divide the pitch into the same number of equal parts, and draw lines perpendicular to those already drawn. Pass a smooth curve through the points of intersection of these lines, forming the continuous diagonal. In Fig. 69-A the helix is a "right-hand helix." The upper part of Fig. 69-B shows a left-hand helix, the motion of

rotation causing a movement up on the front view. The ordinary screw thread used in machinery is a very short-pitched right-hand helix. It is so short indeed that it is customary to represent the curve by a straight line passing through those points which would

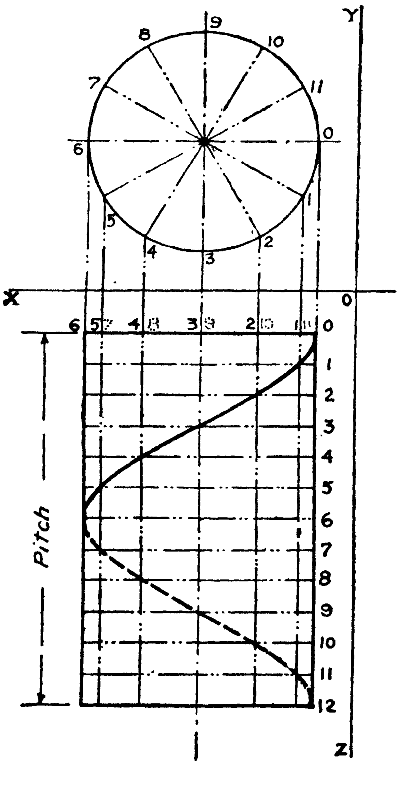


FIG. 69-A.

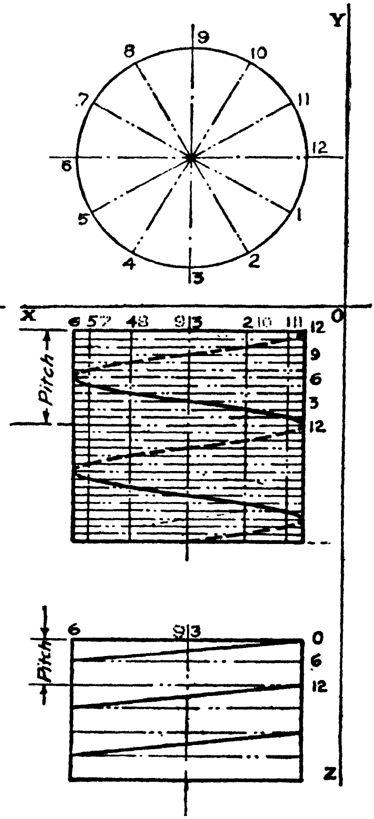


FIG. 69-B.

be given if the construction were reduced to dividing the circumference and the pitch into two equal parts, only. This is shown in the lower part of Fig. 69-B, where points 0, 6 and 12, only, have been used. This is a right-hand thread. The movement is *down* for a clockwise rotation.

The concealed portion of the helix is omitted entirely. This is the usual practice in professional drafting work.

78. The Helicoidal Surface.—If a line, straight or curved, is made to revolve uniformly about an axis and to move uniformly along it, at the same time, every point on the line will generate a helix of the same pitch. The whole line sweeps up a "Helicoidal Surface."

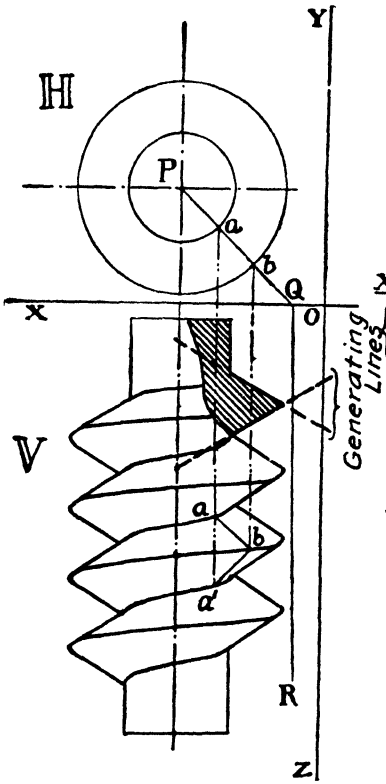


FIG. 70-A.

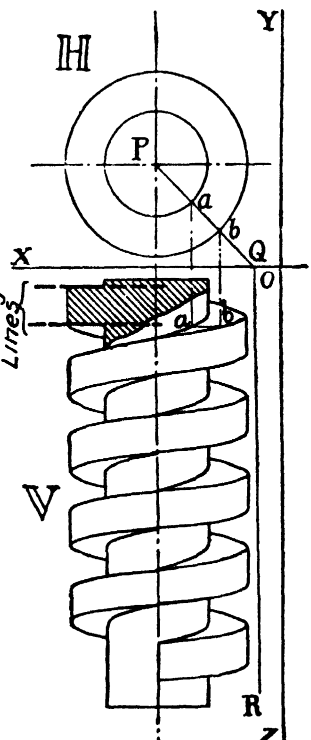
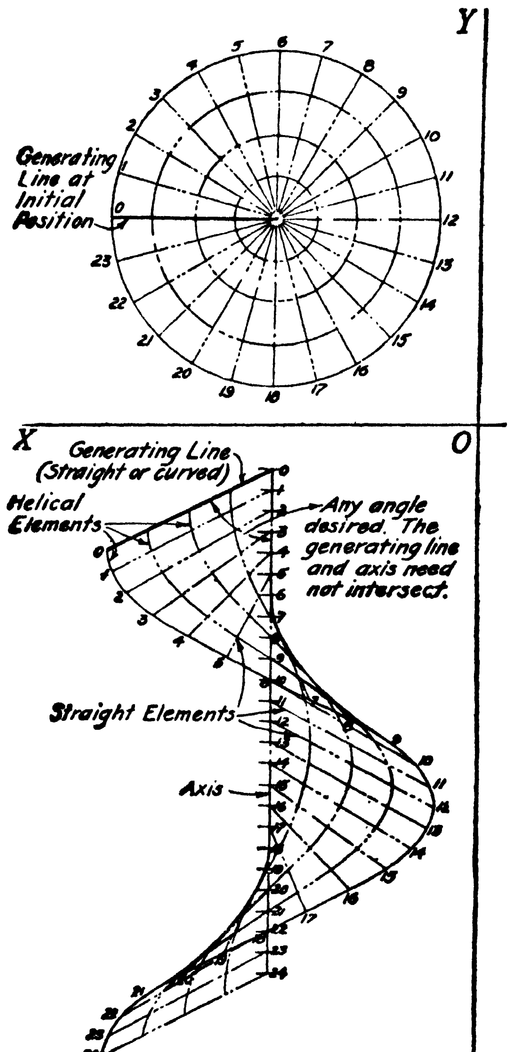


FIG. 70-B.

Usually the generating line is straight and intersects the axis. Fig. 70-A shows a sharp V-thread, a ridge of metal around a cylinder bounded by two helicoidal surfaces whose generating lines make angles of 60° with the axis. Fig. 70-B shows a square thread. The generating lines are perpendicular to the axis.



Generalized Form of the Helicoidal Surface.

FIG. 70-C.

In Fig. 70-C, opposite, the generalized helicoidal surface is shown. The generating line may make any angle with the axis and may extend even to the axis.

In the complete revolution shown on H, the generating line has been described in twenty-four positions at equal angles of 15°, numbered from 0 to 23. On V the 24 positions of the generating line are shown with corresponding numbers.

Four spots on the generating line have been marked and the individual helices they generate described.

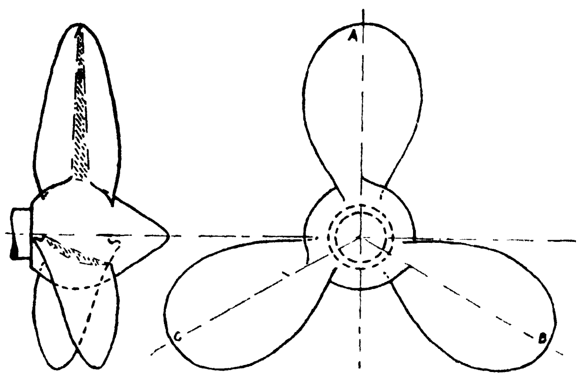


FIG. 70-D

In practice it is very rare to have the surface extend to the axis. There is usually a considerable "core cylinder" as on the propeller on this page.

The marine screw propeller usually has a "driving surface" much like that of 70-C. The generating line may be perpendicular to the axis or may "rake aft." The core cylinder is much smaller than the cores of Figs. 70-A and 70-B and is often modified into a sphere or a stream-lined spheroid. The thickness of the blade is arrived at by calculations for strength and we make no attempt to draw more than the driving surface in this course.

Fig. 70-D is a typical propeller drawing. It shows driving surfaces and two "phantom sections." One gives the thickness of the "backbone" of the blade and one the "root thickness." In Sheet 17, of p. 378, these sections are omitted.

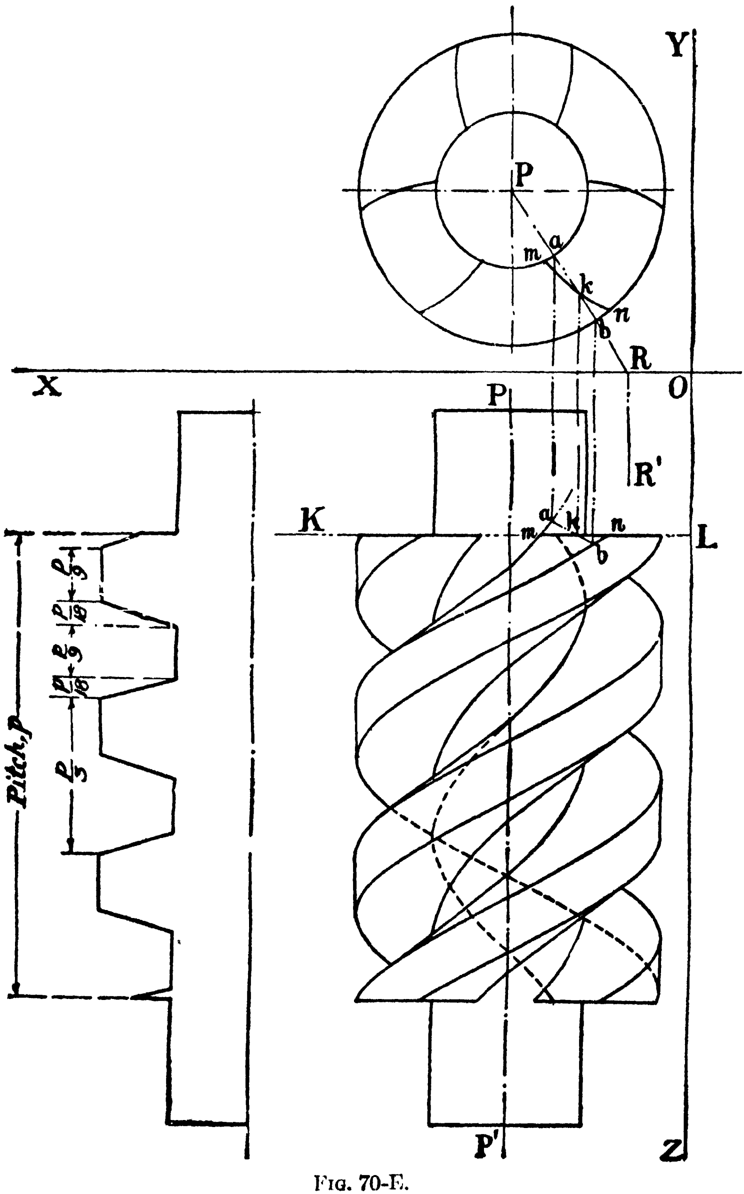


FIG. 70-E.

79. Intersection of a Helicoidal Surface and a Plane.—In Fig. 70-E there is shown a long-pitched screw having a triple thread, such as is often employed for a "worm." To the left is shown a partial longitudinal section giving the generating lines. In $\mathbb{V}$ the concealed parts of the helical edges are omitted, except in the cases of one of the smaller and one of the larger edges. The plane whose trace on $\mathbb{V}$ is KL is perpendicular to the axis, and terminates the screw threads. The intersection of this plane with the screw threads is the curve of intersection to be drawn on $\mathbb{H}$. It is determined by passing planes containing the axis of the worm. One of these is shown by its traces PR and RR'.

From points a and b in the plan corresponding points are plotted on the front elevation, a falling on the helix of small diameter (extended in this case), and b on the helix of large diameter. This element ab of the helix is seen to pierce the plane KL at k. This point k is projected to the plan and is one of the points on the required curved mkn.

Problems VIII.

82. Make the descriptive drawing of a helix whose axis is perpendicular to $\mathbb{S}$ through the point (0, 7, 7) and pitch is 12. The initial point is (2, 7, 2) and the helix is a right-hand one. Draw the $\mathbb{H}$ and $\mathbb{V}$ projections and number points in sequence.

83. The line P (8, 8, 2), P' (8, 8, 14) is the axis of a right circular cylinder of 6 units diameter. Projecting from the cylinder is an helicoidal surface, of 12 units pitch, of which G (5, 8, 2), G' (1, 8, 2) is the generating line. The helicoid is intersected by a plane perpendicular to $\mathbb{H}$ whose trace in $\mathbb{H}$ passes through the points (5, 0, 0) and (16, 11, 0). Draw the plan and front elevation of the cylinder and helicoid and plot the line of intersection with the plane. Use a unit of $\frac{1}{2}''$ or more for this problem.

84. The helicoidal surface of Problem 83 is intersected by a right circular cylinder whose axis Q (12, 8, 2), Q' (12, 8, 14) is parallel to PP'. The radius of the cylinder is 3 units. Draw the line of intersection. Use a unit of $\frac{1}{2}''$ or more for this problem.

85. The axis of a right-hand helicoidal surface is P (16, 16, 0), P' (16, 16, 24). The generating line is P (16, 16, 0), a (12, 16, 2),

b (8, 16, 4), *c* (4, 16, 6), *d* (0, 16, 8). Draw one complete turn pitch 24, $\mathbb{H}$ and $\mathbb{V}$ views only. It is similar to Fig. 70*C* on p. 300.

Sheets 17 and 18 described on pages 378 to 381 are designed to be executed at this place in the study of the subject.

CHAPTER IX.

DEVELOPMENT OF CURVED SURFACES.

80. Meaning of Development as Applied to Curved Surfaces.— Many curved surfaces may be developed on a plane in a manner similar to the development of prisms and pyramids explained in Article 40, page 247. By development, is meant flattening out, without *stretching or otherwise distorting the surface.* If a curved surface is developed on a plane and this portion of the plane, called "the development of the surface," is cut out, this development may

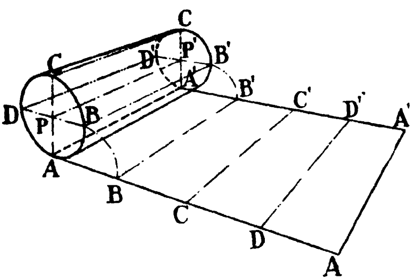


FIG. 71.

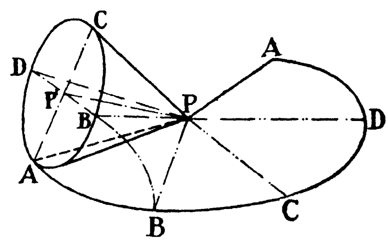


FIG. 72.

be bent into the shape of the surface itself. The importance of the process comes from the fact that many articles of sheet metal are so made. If a sheet of paper is bent in the hands to any fantastic shape, it will always be found that through every point of the paper a straight line may be drawn on the surface in some one direction, the greatest curvature of the surface at this point being in a direction at right angles to this straight line element through the point. The surfaces which can be formed by twisting a plane surface without distortion are called surfaces of single curvature. The curved surfaces, therefore, which are capable of development are only those which are surfaces of single curvature and have straight line elements, but not by any means all of these. All forms

of cylinders and cones, right circular, inclined circular, or non-circular, may be developed. Figs. 71 and 72 show the surfaces unrolling, but working developments are viewed from outside, always.

81. Rectification of the Circular Arc and the Inverse Process.—In Part I, in Arts. 127, 128 and 129 processes for rectifying an arc less than 60°, rectifying a quadrant, and for finding an arc (less than 60°) equal to a given line, were given. These are much used in connection with developments. Two figures repeated here from Part I are reminders of those processes. In Fig. 73-A, $AE=\frac{1}{2}AB$, and in Fig. 74, $AD=\frac{1}{4}AB$.

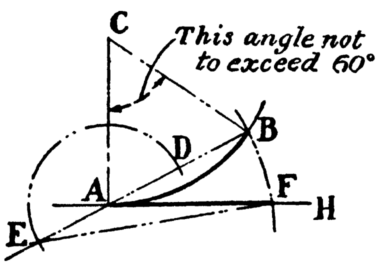


FIG. 73-A.

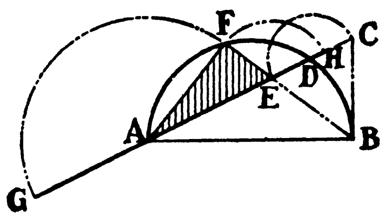


FIG. 73-B.

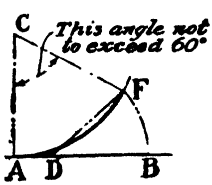


FIG. 74.

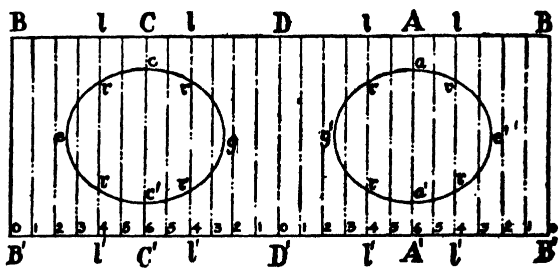


FIG. 75.

82. Rectification of a Semicircle. Pierce's Method.—Fig. 73-B shows a method of rectifying a semicircle to the theoretical accuracy of one part in twenty thousand, which exceeds all practical requirements. The semicircle AFB has a tangent BC, equal to the radius, at one end. Join AC. AC cuts AFB at D. Lay off $DE=DC$. Join BE and extend it to F. Join AF. The periphery of the shaded triangle is equal in length to the semicircle AFB.

Fig. 73 shows this periphery straightened into one line GH ($GA=AF$ and $EH=EF$).

83. Development of a Straight Circular Cylinder.—In Fig. 56 let the intersecting cylinders represent a large sheet-iron ventilating pipe, with two smaller pipes entering it from either side. Such a piece is called by pipe fitters a "cross." The problem is to find the shape of a flat sheet of metal which, when rolled up into a cylinder, will form the surface of the vertical pipe, with the openings already cut for the entrance of the smaller pipes. Before developing the large cylinder, it must be considered as cut on the straight element BB'. After the pipe is formed from the development used as a pattern, the element BB' will be the location of a longitudinal seam.

A rectangle, Fig. 75, is first drawn, the height BB' being equal to the height of the cylinder and the horizontal length being equal to the circumference of the base $BCDA$. (This length may be best found by Mr. Pierce's method, which gives the half-length, BD.) On the drawing, Fig. 56, the base $BCDA$ must be divided into equal parts, 24 parts being usually taken, as they correspond to arcs of 15°, which are easily and accurately constructed with the draftsman's triangles. Only 6 of these 24 parts are required to be actually marked on Fig. 56, as the figure is doubly symmetrical and each quadrant is similar to the others. On Fig. 75 the line $BCDAB$ is divided into 24 parts also, the numbering of the lines of division running from 0 to 6 and back to 0 for each half-length of the development. In V of Fig. 56, draw the elements corresponding to the points of division. The element ll' already drawn corresponds to No. 4, and BB' and CC' correspond to Nos. 0 and 6. The others are not drawn in Fig. 56, to avoid complicating the figure, but would have to be drawn in practice before constructing the development. On the four elements which are numbered 4 on the development, Fig. 75, lay off the distances lr equal to lr in Fig. 56. On the two elements, Fig. 75, numbered 6, lay off Cc or Aa equal to Cc of Fig. 56, and imagine the proper distances to be laid off on elements numbered 3 and 5. Smooth curves through the points thus plotted are the ovals which must be cut out of the sheet of metal to give the proper-shaped openings for the small pipes.

When it is known in advance that the surface of such a cylinder as that in Fig. 56 must be developed, it is often possible to so choose the system of auxiliary intersecting planes used to define the curve of intersection as to give the required equally spaced straight elements for the development.

The smaller cylinder may be developed in the same way. A new

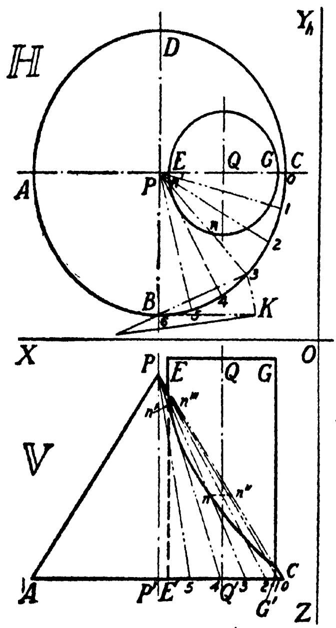


FIG. 76-A.

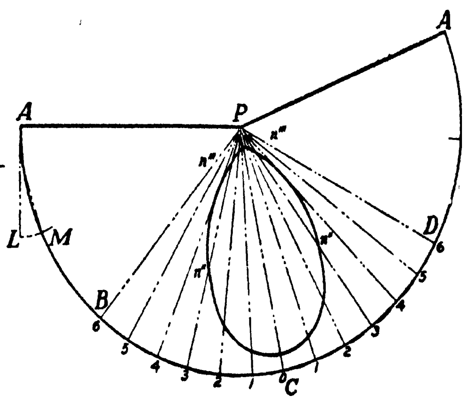


FIG. 76-B.

system of equally spaced straight elements would probably have to be chosen for this cylinder.

84. Development of a Right Circular Cone.—The cone of Figs. 58-A and 58-B on pages 282-B and 283-A is chosen for this illustration. A set of equally spaced straight elements of the cone may have been used in finding the curve of intersection. If they have not been drawn already they must now be put there.

Fig. 76-A repeats all that is needed of those figures and shows the equally spaced elements on *H* and *V*. Imagine the surface of the cone to be cut on the line *PA* and to be flattened out. It now forms the sector of a circle whose radius is *PA*, the slant height of the cone, and whose arc, *ABCDA*, is equal to the circumference of the base of the cone. Any standard method may be used for determining this arc.

On Fig. 76-A, for example, an arc of 45° of the base of the cone has been rectified by the method of Fig. 73-B, page 306, as the line *BK*. On Fig. 76-B the tangent *AL*, equal to *BK*, has been converted to the arc *AM*. See Fig. 74, page 306. *AM*, repeated eight times, gives the arc *ABCDA*. *B*, *C* and *D* are located on the sector, and *BC* and *CD* subdivided to correspond to *BC* of the plan view.

On the development *only true lengths* may be recorded. On element No. 3 points of intersection are at n and n'. Imagine $P3$ on *H* to be rotated 45° counterclockwise so that it takes the place of *PC*. On *V* n and n' move horizontally to the right to n'' and n'''. Pn'' and Pn''' are true lengths and are recorded on the development as shown. The rest is obvious.

If the ratio of *PA* to *P'A* in *V*, Fig. 76-A, can be exactly determined, the most accurate method of getting the angle of the sector is by calculation, for the degrees of arc in the development are to the degrees in the base of the cone (360°) as the radius of the base of the cone is to the slant height. In this case *P'A* is $\frac{9}{16}PA$. The sector in Fig. 76 subtends $\frac{9}{16} \times 360° = 202\frac{1}{2}°$. In the use of this method a good protractor is required to lay out the arc.

85. Intersection of a Cone and a Non-Circular Cylinder.—A class of surfaces known as non-circular cylinders may well be described here. They are a mathematical extension of the idea of the circular and elliptical cylinders and, like them, **may be developed.** A non-circular cylinder is a surface created by a line which moves **always parallel to itself**, being guided by a curve lying in a plane perpendicular to the generating line. This curve, called the *directrix*, is usually a closed curve. The cross-section of such a cylinder is everywhere similar to the directrix.

This fact may be utilized to advantage in some cases. In Fig. 77, an oblique cone and a non-circular cylinder intersect. The directrix of the cylinder is a pointed oval curve, *abcd* in $\mathbb{H}$. Horizontal planes, as *T'T*, intersect the cylinder in a curve identical in shape with its directrix, so that its projection on $\mathbb{H}$ coincides with the projection of the directrix on $\mathbb{H}$. The intersection with the cone is a circle, *mt'tn*, and the intersections of the intersections are the points *t* and *t'* in front, and two corresponding points behind.

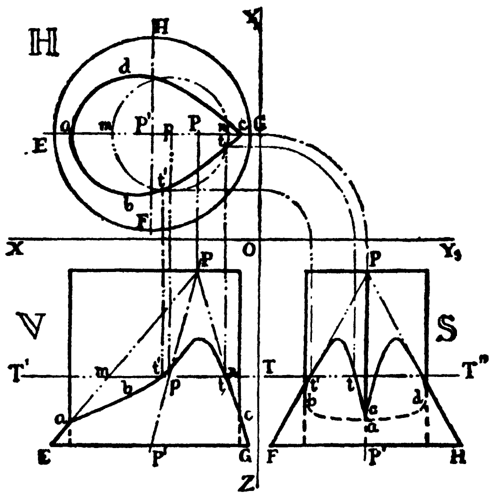


FIG. 77.

Problems IX.

86. Draw an arc of 60° with 10 units radius. At one end draw a tangent and on the tangent lay off a length equal to the given arc. On the tangent lay off a length of 8 units, and find the length of arc equal to this distance.

87. An arc of 12 units radius, one of 9 units radius, and a straight line are all tangent at the same point. Find on the tangent the straight line equal in length to 45° of the large arc. Find the length on the other arc equal to this length on the tangent and show that it is an arc of 60°.

88. Rectify a semicircle of 10 units radius and compare this length with the calculated length, 31.4 units.

89. A rectangle 31.4 units by 12 units is the developed area of a cylinder of 10 units diameter. A diagonal line is drawn on the development, which is then rolled into cylindrical form. Plot the form taken by the diagonal and show that it is a helix, pitch 12.

90. A right circular cone has a base of 10 units diameter, and a vertical height of 12 units. Its slant height is 13 units. Calculate the angle of the sector which is the developed surface of the cone. Find this angle by rectifying the circumference of the base of the cone, and by finding the arc equal to the rectified length.

91. A semicircle, radius 10 units, is rolled up into a cone. What is the radius of the base? What is the slant height? What is the relation between the area of the curved surface of the cone and the area of the base?

92. A right circular cylinder, such as Fig. 49, is of 7.59 units diameter, and 12 units height. It is intersected by a plane perpendicular to $\mathbb{V}$ through the points C' and A'. Draw plan, front elevation and the development of the surface.

93. A right circular cone, like that of Fig. 51, has its front elevation an equilateral triangle, each side being 10 units in length. From A_v a perpendicular is drawn to P_vC_v cutting it at E. If this line represents a plane perpendicular to $\mathbb{V}$, draw the development of the cone with the line of intersection of the cone and plane on it.

94. A right circular cylinder, standing in a vertical position, as in Fig. 49, diameter 7 units, and length 10 units, is pierced from side to side by a square hole $3\frac{1}{2}$ units on each edge, the axis of the hole and the axis of the cylinder bisecting each other at right angles. Draw the development of the surface.

95. A sheet of metal 22 units square with a hole 11 units square cut out of its middle, the sides of the hole being parallel to the edges of the sheet, is rolled up into a cylinder. Draw three views.

96. A non-circular cylinder has its straight elements, length 16 units, perpendicular to $\mathbb{H}$. The directrix is a smooth curve through the points A (14, 6, 0), B (12, 4, 0), C (10, 4, 0), D (8, 5, 0), E (5, 8, 0), F (2, 13, 0). It is pierced by a cylinder having its base in $\mathbb{V}$, axis perpendicular to $\mathbb{V}$ at the point (8, 0, 8), radius 5 units, and length 14. Find the line of intersection in $\mathbb{S}$.

(Problems 97, 98 and 99 are best drawn on sheets of paper, 11″ × 15″ or larger.)

97. Fig. 77*b* represents a tin funnel made in the form of two truncated cones soldered together. Piece *A*, when developed, has an inner radius of $3\frac{1}{16}''$ and an outer radius of $6\frac{1}{8}''$. Piece *B* has an inner radius of $1\frac{1}{4}''$ and an outer one of 5″. Draw the developments full size.

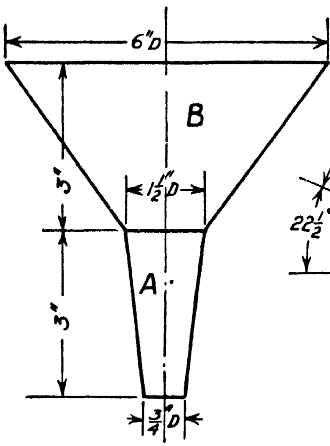


FIG. 77*b*

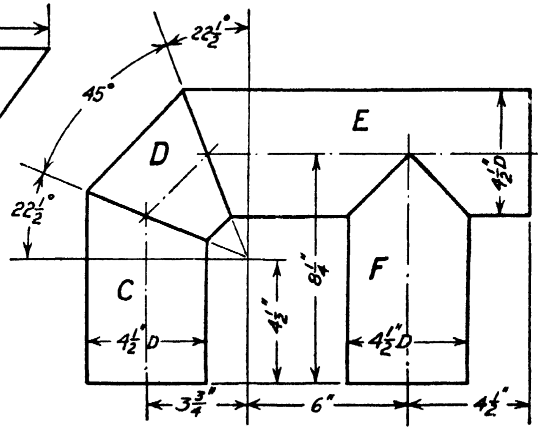


FIG. 77*c*.

98. Fig. 77*c* represents an air duct of sheet metal made of pieces *C, D, E* and *F*. Draw the developments of pieces *C* and *D* to the scale of 4″ = 1 foot.

99. To the scale of 4″ = 1 foot draw the development of piece *F*.

Sheets 19 and 20, described on page 382, are designed to be executed at this place in the study of the subject.

CHAPTER X.

STRAIGHT LINES OF UNLIMITED LENGTH AND THEIR TRACES.

86. Negative Coordinates.—We have dealt only with points having positive or zero coordinates, and the lines and planes have been

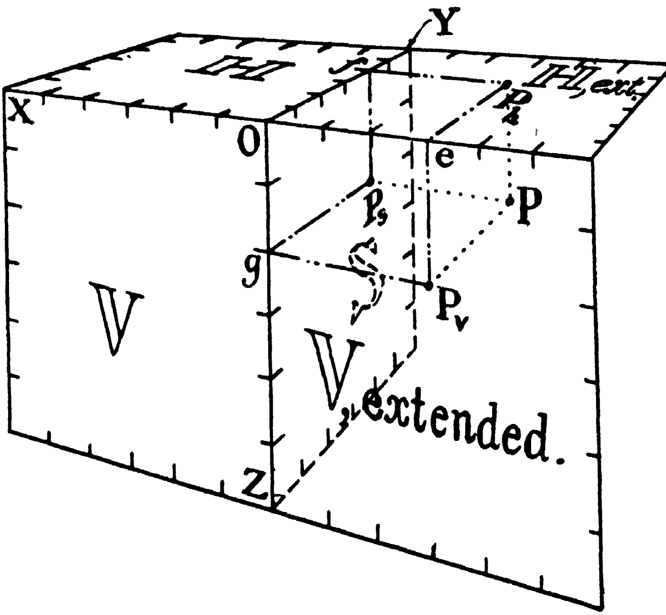


FIG. 78.

limited in their extent, or, if infinite, have extended indefinitely only in the positive directions. As it becomes necessary at times to trace lines and planes in their course, no matter if they cross the reference planes into new regions of space, the use and meaning of negative coordinates must be explained. The value of the x coordinate of a point is the length of the $\mathbb{S}$ projector or perpendicular distance from the point to the side reference plane $\mathbb{S}$. (See Figs. 6 and 7, Art. 9.) If this value decreases gradually to zero,

the point moves towards $\mathbb{S}$ until it lies in $\mathbb{S}$ itself. If this value becomes negative, it is clear that the point crosses the side reference plane into a space to the right of it.

For example, a point P, having a variable x coordinate, but having its y coordinate always equal to 4 and its z coordinate equal to 2, is a point moving on a line parallel to the axis of X. If x decreases to zero, it is on $\mathbb{S}$ at the point marked P_s in Fig. 78. If the x coordinate decreases further, reaching a value of -3, it moves to the point P in that figure. Fig. 78 is the perspective drawing of a point P $(-3, 4, 2)$. The y and z projectors cannot project the point P to $\mathbb{H}$ and $\mathbb{V}$ in their customary positions, but

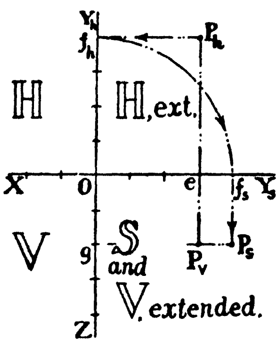


FIG. 79.

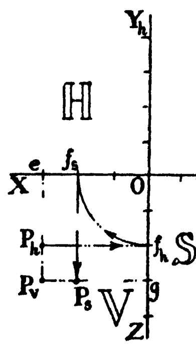


FIG. 80.

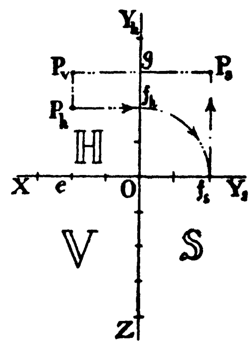


FIG. 81.

project it upon parts of those planes extended beyond the axes of Y and Z, as shown. In Fig. 79, the corresponding descriptive drawing, it must be understood that the plane $\mathbb{H}$, extended, has been revolved with $\mathbb{H}$, about the axis of X, into the plane of the paper, $\mathbb{V}$, and $\mathbb{S}$ has been revolved as usual about the axis of Z, coming into coincidence with $\mathbb{V}$, extended. This "development" of the planes of reference is exactly as described in Art. 7. It is noticeable that the x coordinate of P is laid off to the right of the origin instead of to the left. P_h lies, therefore, in the quadrant which usually represents no plane of projection, and P_v lies in the quadrant which usually represents $\mathbb{S}$. P_s lies in its customary place, since both y and z, the coordinates which alone appear in $\mathbb{S}$, are positive.

It is evident that the laws of projection for $\mathbb{H}$, $\mathbb{V}$ and $\mathbb{S}$, Art. 11, have not been altered, but simply extended. P_h and P_v are in the same vertical line; P_v and P_s are in the same horizontal line; and the construction which connects P_h and P_s still holds good.

In Fig. 79 the space marked $\mathbb{S}$ represents not only $\mathbb{S}$ but $\mathbb{V}$ extended as well.

In Fig. 80 is represented a point P $(3, -2, 3)$, having a negative y coordinate. The point is *in front* of $\mathbb{V}$, at 2 units' distance, not *behind* $\mathbb{V}$. The projection on $\mathbb{H}$, instead of being *above* the axis of X a distancee of 2 units, is *below* it by the same amount. So also the projection on $\mathbb{S}$ is to the *left* of the axis of Z, a distance of 2 units, instead of the the *right* of it. After developing the reference planes in the manner of Art. 7, plane $\mathbb{H}$, extended, has come into coincidence with $\mathbb{V}$, and plane $\mathbb{S}$, extended, has also come into coincidence with $\mathbb{V}$. Thus the field representing $\mathbb{V}$ represents also the other two reference planes, extended.

In Fig. 81 a point P $(2, 2, -3)$ having a negative z coordinate is represented. The point is *above* $\mathbb{H}$ 3 units, instead of *below* $\mathbb{H}$, at the same perpendicular distance. P projects upon $\mathbb{V}$ on $\mathbb{V}$ extended above the axis of X. After developing the reference planes, plane $\mathbb{H}$ comes into coincidence with $\mathbb{V}$ extended. P_s is on $\mathbb{S}$ extended above the axis of Y, and therefore after development it occupies the so-called "construction space."

Points having two or three negative coordinates may be dealt with in the same manner, but are little likely to arise in practice.

It is evident that subscripts must be used invariably, to prevent confusion whenever negative values are encountered.

87. Graphical Connection Between P_h and P_s.—In Figs. 79, 80 and 81, P_h and P_s are connected by a construction line $P_hf_hf_sP_s$ in a manner which is an extension of that shown by Fig. 7, Art. 9. Note that the quadrant of a circle connecting P_h and P_s must be described always on the construction space or on the field devoted to $\mathbb{V}$, never on the fields devoted to $\mathbb{H}$ or $\mathbb{S}$.

88. Traces of a Line of Unlimited Length, Parallel to an Axis.—A straight line which has no limit to its length, but extends indefinitely in either direction, must necessarily have some points whose coordinates are negative. In passing from positive to nega-

tive regions the line must pass through some plane of reference (having one of its coordinates zero at that point), and the point where it pierces a plane of reference is called the *trace* of the line on that plane of reference, the word trace being used to indicate a "track" or print showing the passage of the line.

Lines parallel to the axes have been used freely already. An ℍ projector is simply a vertical line or line parallel to the axis of Z. Any perspective figure showing a point P and its horizontal projection P_h will serve as an illustration of this line, as PP_h in Fig. 6, Art. 9.

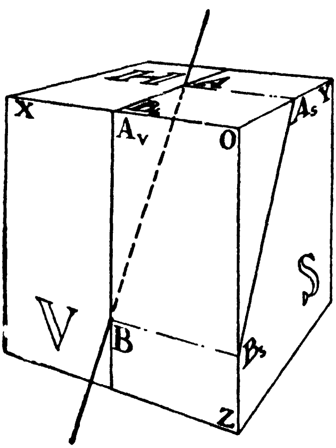


FIG. 82.

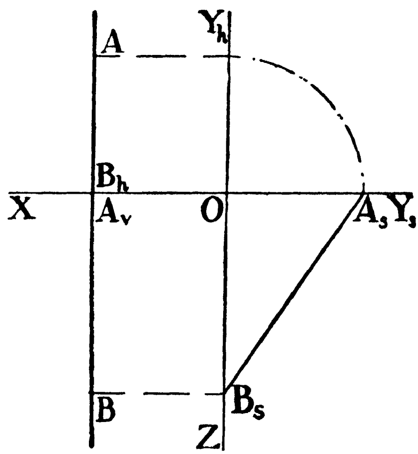


FIG. 83.

Imagine PP_h to be extended in both directions as an unlimited straight line. Then P_h is the trace of the line on ℍ. In Fig. 7, the point P_h itself is the ℍ projection of the line. P_ve, extended in both directions, is the vertical projection and P_sf_s is the side projection. Thus it is seen that a vertical line has but one trace, that on the plane to which it is perpendicular. PP_v may be taken as an illustration of a line parallel to the axis of Y, and PP_s of one parallel to the axis of X. A better example of this latter case is shown in Figs. 15 and 16, Art. 16. The line BAA_s, perpendicular to 𝕊, has its trace on 𝕊 at A_s.

89. Traces of an Inclined Straight Line.—An inclined line such as AB in Figs. 82 and 83 pierces two reference planes as at A and B, but as it is parallel to the third reference plane, $\mathbb{S}$, it has no trace on $\mathbb{S}$. The peculiarity of the descriptive drawing of this line, Fig. 83, is the apparent coincidence of the $\mathbb{H}$ and $\mathbb{V}$ projections as one vertical line. The $\mathbb{S}$ projection is required to determine the traces A and B.

90. Traces of an Oblique Straight Line: The $\mathbb{H}$ and $\mathbb{V}$ Traces.—An oblique line, if unlimited in length, must pierce each of the reference planes, since it is oblique to all three. Any line is com-

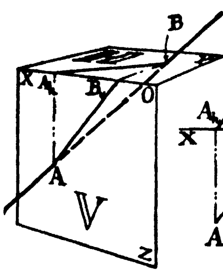


FIG. 84.

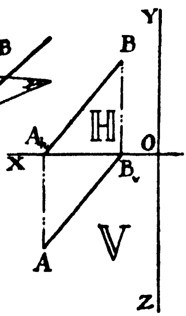


FIG. 85.

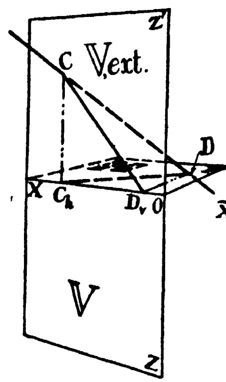


FIG. 86.

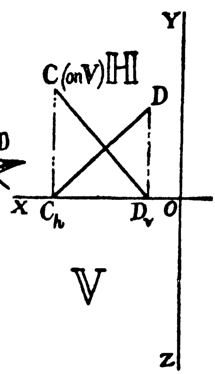


FIG. 87.

pletely defined when two points on the line are given. If two traces of a straight line are given, the third trace cannot be assumed, but must be constructed from the given conditions by geometrical process. It will always be found that of the three traces of an oblique line one trace at least has some negative coordinate.

As the complete relation between the three traces is somewhat complicated, the relation between two traces, as, for instance, $\mathbb{H}$ and $\mathbb{V}$ traçes, must be considered first. Two cases are shown, the first by Figs. 84 and 85, and the second by Figs. 86 and 87. The line AB is the line whose traces are A $(5, 0, 4)$ and B $(2, 4, 0)$. The line CD is the line whose traces are $C(7, 0, -5)$ and D $(2, 4, 0)$.

From the descriptive drawing of AB, Fig. 85, it is seen that the H projection of the line cuts the axis of X vertically above the trace on V, and that the V projection cuts the axis of X vertically under the trace on H. It may be noted that the two right triangles A_hBB_v and B_vAA_h have the line A_hB_v on the axis of X as their common base. From the descriptive drawing of the line CD, Fig. 87, it is seen that the effect of the vertical trace C having a negative z coordinate simply puts C (on V) above C_h, instead of below it. The two right triangles C_hDD_v and D_vCC_h have the line C_hD_v on the axis of X, as their common base, but the latter triangle is above the axis instead of in its normal position.

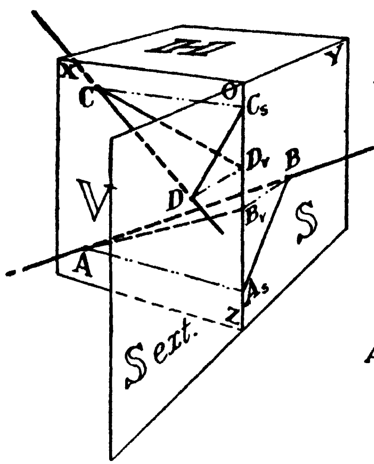


FIG. 88.

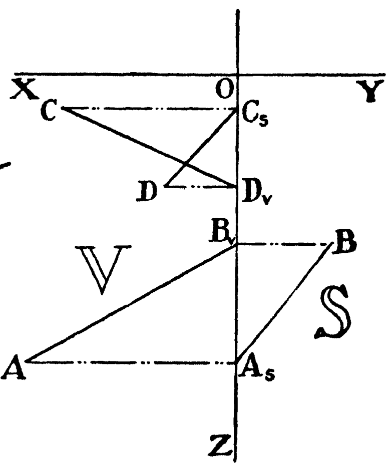


FIG. 89.

91. Traces of an Oblique Straight Line: The V and S Traces.— Figs. 88 and 89 show two lines piercing V and S.

The line AB pierces V at A and S at B. The two right triangles A_sAB_v and B_vBA_s have their common base A_sB_v on the axis of Z.

The line CD pierces V at C and S extended at D, the point D having a negative y coordinate. The right triangles C_sCD_v and D_vDC_s have their base D_vC_s in common on the axis of Z, but in the descriptive drawing D_vDC_s lies to the left of the axis of Z instead of to the right, owing to the point D having a negative y coordinate.

92. Traces of an Oblique Straight Line: The H and S Traces.—Figs. 90 and 91 show two lines piercing H and S.

The line AB pierces H at A and S at B. The triangles A_sAB_h and B_hBA_s have their common base A_sB_h on the axis of Y, Fig. 90, but in the descriptive drawing the duplication of the axis of Y causes this base A_sB_h to separate into two separate bases, one on OY_h and one on OY_s. Otherwise, there has been no change.

The line CD pierces H at C and S extended at D, the point D having a negative z coordinate. In Fig. 90 C_sCD_h and D_hDC_s have

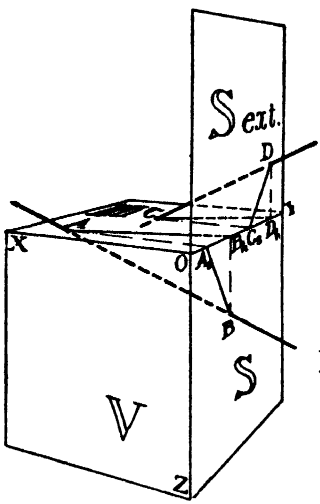


FIG. 90.

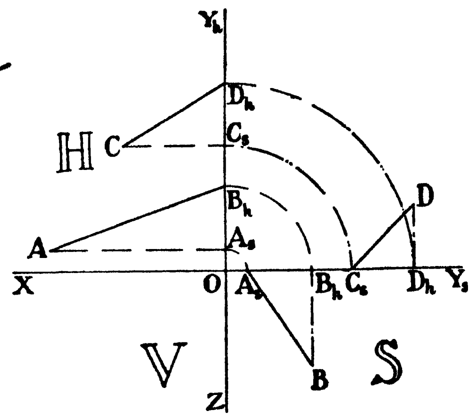


FIG. 91.

their common base C_sD_h on the axis of Y, but in the descriptive drawing C_sD_h appears in two places. The triangle D_hDC_s lies above S in the "construction space," or on S extended, since D has a negative z coordinate.

93. Three Traces of an Oblique Straight Line.—Figs. 92 and 93 show an oblique straight line ABC piercing V at A, H at B, and S extended at C. Since the line is straight, the three projections of the line AB_vC_v, A_sB_sC and A_hBC_h are all straight lines. In the perspective drawing, Fig. 92, part of the V projection is on V extended and part of the S projection on S extended.

In the descriptive drawing, Fig. 93, the relation between A and B is the same as that in Fig. 85, as shown by the two triangles A_hAB_v and B_vBA_h, or the quadrilateral A_hAB_vB. The relation between A and C, as shown by the quadrilateral A_sAC_vC, is the same as that between A and B, Fig. 89, as shown by the quadrilateral A_sAB_vB. The relation between B and C, Fig. 93, as shown by the two triangles B_sBC_h and C_hCB_s, is the same as that between C and D of Fig. 91, as shown by the triangles C_sCD_h and D_hDC_s. No new feature has been introduced.

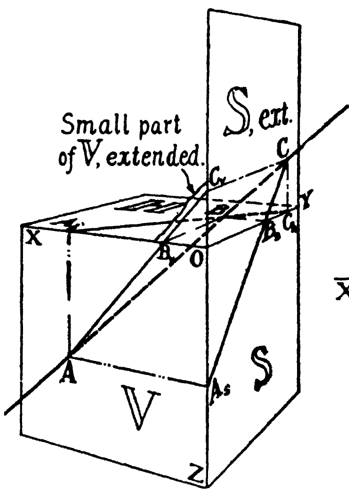


FIG. 92.

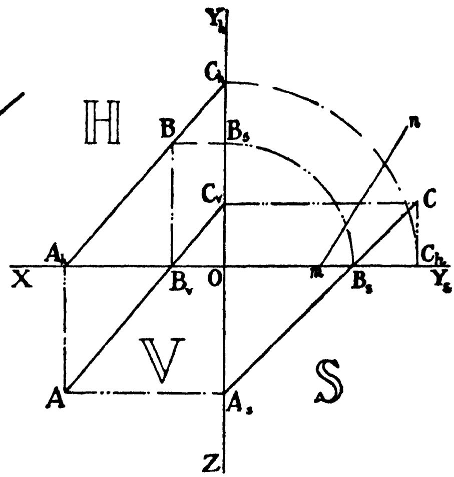


FIG. 93.

94. Paper Box Diagram.—To assist in understanding Figs. 92 and 93, a model in space should be made and studied from all sides. The complete relation of the traces is then quickly grasped. Construct the descriptive drawing, Fig. 93, on coordinate paper, using, as coordinates for A, B and C, $(15, 0, 12)$, $(5, 12, 0)$, and $(0, 18, -6)$. Fold into a paper box after the manner of Fig. 9, Art. 12, having first cut the paper on some such line as mn, so that the part of the paper on which C is plotted may remain upright, serving as an extension to $\mathbb{S}$. It will be found that a straight wire or long needle or a thread may be run through the points A, B and C, thus producing a model of the line and all its projections.

95. Intersecting Lines.—If two lines intersect, their point of intersection, when projected upon any plane of reference, must necessarily be the point of intersection of the projections on that plane. For example, a line AB intersects a line CD at E. Project E upon a plane of reference, as $\mathbb{H}$. Then E_h must be the point of intersection of A_hB_h and C_hD_h. In the same way E_v must be the point of intersection of A_vB_v and C_vD_v, and E_s of A_sB_s and C_sD_s.

To determine whether two lines given by their projections meet in space or pass without meeting, the projections on at least two reference planes must be extended (if necessary) till they meet. Then for the lines themselves to intersect, the points of intersection of the two pairs of projections must obey the rules of projection of a point in space (Art. 11). Thus if A_hB_h and C_hD_h are given and meet at a point vertically above the point of intersection of A_vB_v and C_vD_v, the two lines really meet at a point whose projections are the intersections of the given projections. If this condition is not filled the lines pass without meeting, the intersecting of the projections being deceptive.

96. Parallel Lines.—If two lines are parallel, the projections of the lines on a reference plane are also parallel (or coincident). For, the two lines make the same angle with the plane of projection; their projector-planes are parallel; and the projections themselves are parallel.

Thus if a line AB is parallel to another line CD, then A_hB_h must be parallel to C_hD_h, A_vB_v to C_vD_v, and A_sB_s to C_sD_s. If the two lines lie in a plane perpendicular to a plane of projection—for example, perpendicular to $\mathbb{H}$—then the $\mathbb{H}$ projector-planes coincide and the $\mathbb{H}$ projections also coincide. The $\mathbb{V}$ and $\mathbb{S}$ projections are parallel but not coincident.

If two lines do not fill the conditions of intersecting or of parallel lines, they must necessarily be lines which pass at an angle without meeting.

Problems X.

100. Plot the points A $(8, 6, -4)$, B $(7, -3, 5)$, C $(-7, 0, 12)$.

101. Plot the points A $(6, -10, 3)$, B $(0, 0, -8)$, C $(-6, 5, 4)$.

102. Make a descriptive drawing of a line 26 units long from the point P $(-8, 4, 9)$, perpendicular to $\mathbb{S}$. What traces does it have? What are the coordinates of its middle point?

103. A line is drawn from P $(12, 5, 16)$ perpendicular to $\mathbb{H}$. Make the descriptive drawing of the line, and of a line perpendicular to it, drawn from Q $(0, 0, 8)$. What is the length of this perpendicular line, and where are its traces?

104. A straight line extends from A $(8, 12, 0)$ through D $(8, 6, 8)$ for a distance of 20 units. Make the descriptive drawing of the line. Where are its traces and its middle point?

105. A straight line pierces $\mathbb{H}$ at A $(8, 6, 0)$ and $\mathbb{V}$ at B $(8, 0, 12)$. Draw its projections. Where is its trace on $\mathbb{S}$? What are the coordinates of D, its middle point?

106. A straight line extends from E $(15, 6, 16)$ through A $(3, 6, 0)$ to meet $\mathbb{S}$. Make the descriptive drawing and mark the traces on $\mathbb{H}$ and $\mathbb{S}$.

107. Draw the lines A $(16, 11, 8)$, B $(4, 8, 2)$; C $(12, 5, 10)$, D $(0, 2, 4)$; and E $(11, 3, 0)$, F $(5, 15, 8)$. Which pair meet, which are parallel, and which pass at an angle? What are the coordinates of the point of intersection of the pair which meet?

108. The points A $(8, 0, 12)$, B $(0, 8, 6)$ and C $(-8, 16, 0)$ are the traces of a straight line. Make the descriptive drawing of the line.

109. The points A $(8, -4, 0)$, D $(4, 4, 6)$ and E $(2, 8, 9)$ are on a straight line. Find the trace B where it pierces $\mathbb{V}$ and the trace C where it pierces $\mathbb{S}$.

CHAPTER XI.

PLANES OF UNLIMITED EXTENT: THEIR TRACES.

97. Traces of Horizontal and Vertical Planes.—The lines of intersection of a plane with the reference planes are called its traces. Planes of unlimited extent may be of three kinds, parallel to a reference plane, inclined, or oblique. Unlimited planes of the first two classes have been dealt with already, but for the sake of precision may be treated here again to advantage.

A horizontal plane is one parallel to $\mathbb{H}$, and the trace of such a plane on $\mathbb{V}$ is a line parallel to the axis of X, and the trace on $\mathbb{S}$ is a line parallel to the axis of Y. These traces meet the axis of Z at the same point and appear on the descriptive drawing as one continuous line. There is of course no trace on $\mathbb{H}$. In Fig. 53, Art. 64, the plane T, represented by its traces $T'T$ on $\mathbb{V}$ and TT'' on $\mathbb{S}$, is a horizontal plane. These traces are not only the intersections of T with $\mathbb{H}$ and $\mathbb{S}$, but T is "seen on edge" in those views. Every point of the plane T, when projected upon $\mathbb{V}$, lies somewhere on the line $T'T$, extended indefinitely in either direction.

A vertical plane parallel to $\mathbb{V}$ has for its traces a line on $\mathbb{H}$ parallel to the axis of X, and on $\mathbb{S}$ a line parallel to the axis of Z, with no trace on $\mathbb{V}$. These traces meet the axis of Y at the same point, and appear on the descriptive drawing as two lines at right angles to this axis, the point on Y separating into two points as usual. In Fig. 54-C, p. 277, a vertical plane R, parallel to $\mathbb{V}$, is represented by its traces $R'R$ on $\mathbb{H}$ and RR'' on $\mathbb{S}$.

A vertical plane parallel to $\mathbb{S}$ has for its trace on $\mathbb{H}$ a line parallel to the axis of Y, and for its trace on $\mathbb{V}$ a line parallel to the axis of Z, with no trace on $\mathbb{S}$. These traces meet the axis of X at the same point and appear on the descriptive drawing as one continuous line.

98. Traces of Inclined Planes.—Inclined planes are those perpendicular to one reference plane, but not to two reference planes. The auxiliary planes of projection have been of this kind. In Fig. 20, p. 233, the plane $\mathbb{U}$, perpendicular to $\mathbb{H}$, has the line

MX for its trace on $\mathbb{H}$, and XN for its trace on $\mathbb{V}$. In the descriptive drawing, Fig. 22-B, MX and XN_v are these traces.

If in Fig. 20 both $\mathbb{U}$ and $\mathbb{S}$ are imagined to be extended towards the eye, they will intersect in a line parallel to OZ. This $\mathbb{S}$ trace will be on $\mathbb{S}$ extended, and every point of it will have the same negative y coordinate. Of the three traces of $\mathbb{U}$, two are vertical lines, and one only, MX, is an inclined line. The plane in Fig. 64, Art. 71, may be taken as a second example of an inclined plane perpendicular to $\mathbb{H}$. The trace on $\mathbb{S}$ is not a negative line in this case, but is a vertical line on $\mathbb{S}$ to the right of the axis of Z at a distance equal to OJ.

In Fig. 54-A, IJ, JK and KL are the three traces of an inclined plane perpendicular to $\mathbb{V}$. In every case of an inclined plane the inclined trace is on that reference plane to which it is perpendicular, and shows the angles of the inclined plane with one or both of the other reference planes.

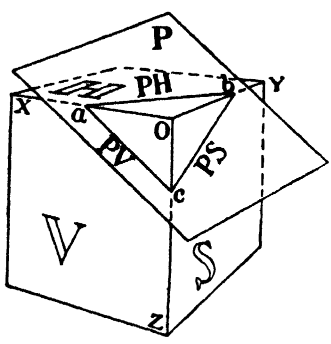


FIG. 94.

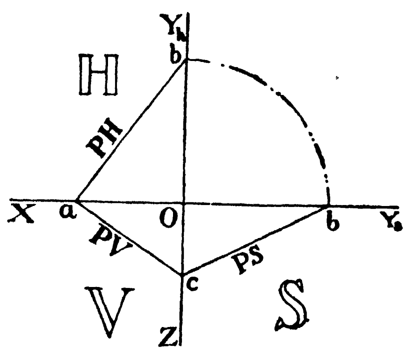


FIG. 95.

99. Traces of an Oblique Plane: All Traces "Positive."—The general case of an oblique plane is shown in Fig. 94. The plane P is represented as cutting the cube of reference planes in the lines marked PH, PV and PS. These lines are the traces of the plane P, and may be understood to extend indefinitely, the plane itself extending in all directions without limit. They are shown limited in Fig. 94 in order to make a more realistic appearance. PH, PV and PS are used to define the three traces.

Where *PH* and *PV* meet we have a point common to three planes, *P*, $\mathbb{H}$ and $\mathbb{V}$. Since it is common to $\mathbb{H}$ and $\mathbb{V}$ it is on the line of intersection of $\mathbb{H}$ and $\mathbb{V}$, or in other words it is on the axis of *X*. This point is marked *a*. In the same way *PH* and *PS* meet at *b* on the axis of *Y*, and *PV* and *PS* meet at *c* on the axis of *Z*.

The descriptive drawing, Fig. 95, is obvious from the explanation of the perspective drawing. From Fig. 95 it is evident that if two traces of a plane are given the third trace can be determined

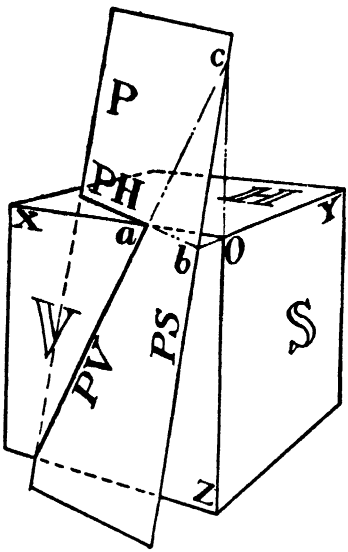


FIG. 96.

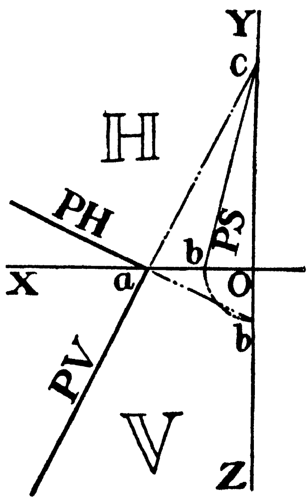


FIG. 97.

by geometrical construction. Thus, if *PH* and *PV* are given, *PS* may be defined by extending *PH* to *b* on the axis of *Y* and extending *PV* to *c* on the axis of *Z*. The line joining *bc* is the required trace of the plane on $\mathbb{S}$. If any two points on one trace are given, and any one point on a second trace, the whole figure may be completed. Thus any two points on *PH* define that line and enable *a* and *b* to be found. A third point on *PV*, taken in conjunction with *a*, defines *PV*, and enables *c* to be located. *bc*, as before, defines the trace *PS*. This is an application of the general principle that three points determine a plane.

100. Traces of an Oblique Plane: One Trace "Negative."—In Figs. 94 and 95 the plane P has been so selected that all traces have positive positions. These are the portions usually drawn. Of course each trace may be extended in either direction, points on the trace then having one or more negative coordinates. Any trace having points all of whose coordinates are positive, or zero, may be called a positive trace.

In Fig. 96 a plane P is shown, intersecting $\mathbb{H}$ and $\mathbb{V}$ in the "positive" traces PH and PV. The third trace, PS, in this case, has no point all of whose coordinates are positive. In the descriptive drawing, Fig. 97, the two positive traces, meeting at a on the

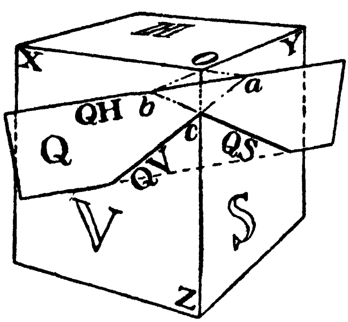


Fig. 98.

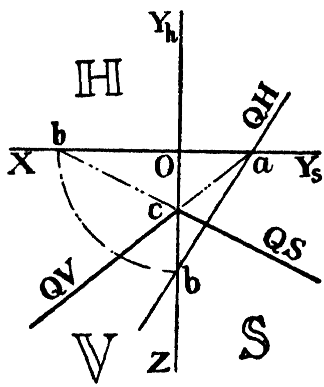


Fig. 99.

axis of X, are usually considered as fully representing the plane P. From these lines PH and PV, alone, the imagination is relied upon to "see the plane P in space," as shown by Fig. 96.

In Fig. 98, the plane Q is represented. Ordinarily the positive traces QV and QS, meeting at c on the axis of Z, are the only traces shown in the descriptive drawing, Fig. 99, and are considered to indicate perfectly the path of the plane Q.

101. Position of the Negative Trace.—The negative trace PS, in Fig. 96, is shown as one of the edges of the rectangular plate representing the unlimited plane P. This line PS has been determined by extending PH to meet the axis of Y (extended) at

b, and by extending PV to meet the axis of Z (extended) at c. The line joining b and c is the trace PS. It will be noted that in finding the location of PS in Fig. 97, PV has been extended to cut the axis of Z (extended up from ZO) at c and PH has been extended to cut the axis of Y (extended down from YO) at b. b has been rotated 90° about the origin, and the points b and c thus plotted (on $\mathbb{S}$ extended) have been found to give the line PS. Every step of the process and the lettering of the figure have been similar to those used in finding PS from PH and PV in Art. 98.

In Fig. 98, the negative trace is QH, the top line of the rectangular plate representing the unlimited plane Q. QH has been determined as follows: QV extended meets the axis of X extended at a, and QS extended meets the axis of Y extended at b. The line ab is therefore the trace on $\mathbb{H}$, or QH. In the descriptive drawing the same process of extending QV to a and QS to b determines the line QH, a line every point of which has some negative coordinate. Of course QH must be considered as drawn on parts of the plane $\mathbb{H}$ extended over $\mathbb{V}$, $\mathbb{S}$, and the so-called construction space. In finding the negative traces, it is imperative to letter the diagrams uniformly, keeping a for the intersection of the plane with the axis of X, b for that with the axis of Y, and c for that with the axis of Z. With this rule b will always be the point which is doubled by the separation of the axis of Y into two lines, and the arc bb will always be described in the construction space or in the quadrant devoted to $\mathbb{V}$, never in those devoted to $\mathbb{H}$ and $\mathbb{S}$.

102. Parallel Planes.—If two planes are parallel to each other, their traces on $\mathbb{H}$, $\mathbb{V}$ and $\mathbb{S}$ are parallel each to each. This proposition may be proved as follows: If we consider two planes P and Q parallel to each other and each intersecting the plane $\mathbb{H}$, the lines of intersection with $\mathbb{H}$ (PH and QH) cannot meet, for, if they did meet, the planes themselves would meet and could not then be parallel planes. PH and QH must therefore be parallel lines described on $\mathbb{H}$. Thus, if a plane P and a plane Q are parallel, then PH and QH are parallel, PV and QV are parallel, and PS and QS are parallel.

The method of finding the true length of a line by its projection upon a plane parallel to itself, treated in Chapter II, is really the

process of passing a plane parallel to a projector-plane of the given line. Thus in Fig. 22-B, p. 234, the auxiliary plane 𝕌 has its horizontal trace XM parallel to A_hB_h, and the vertical trace of the ℍ projector-plane, if drawn, would be parallel to XN_v.

103. The Plane Containing a Given Line.—If a line lies on a plane, the trace of the line on any plane of reference (the point where it pierces the plane of reference) must lie on the trace of the plane on that plane of reference. Thus, if the line EF, Fig. 100, lies on the plane P, then A, the trace of EF on ℍ, lies on PH, the trace of P on ℍ; and B, the trace of EF on 𝕍, lies on PV, the trace of P on 𝕍.

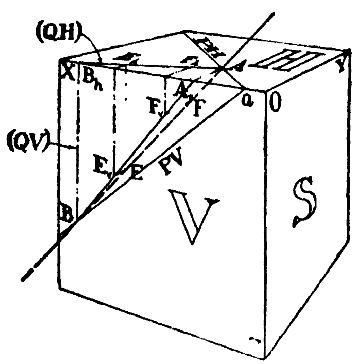


FIG. 100.

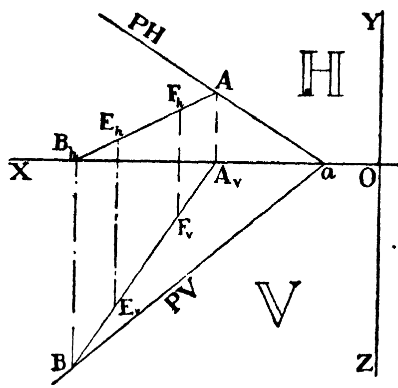


FIG. 101.

From this fact it follows that to pass a plane which will contain a given line it is necessary to find two traces of the line and to pass a trace of the plane through each trace of the line. As an infinite number of planes may be passed through a given line, it is necessary to have some second condition to define a single plane. For example, the plane may be made also to pass through a given point or to be perpendicular to a reference plane.

In Fig. 100, if only the line EF is given and it is required to pass a plane P, containing that line, and containing also some point, as a, on the axis of X, the process is as follows: Extend the line EF to A and B, its traces on ℍ and 𝕍. Join Ba and aA. These

are the traces of the required plane P. In the descriptive drawing, Fig. 101, the corresponding operation is performed. A and B must be determined as in Art. 90, and joined to a. These lines represent the traces of a plane containing the line EF and the chosen point a.

To pass a plane Q containing the line EF and also perpendicular to $\mathbb{H}$ (Figs. 100 and 101), the trace of Q on $\mathbb{H}$ must coincide with the projection of EF on $\mathbb{H}$, for the required plane perpendicular to $\mathbb{H}$ is the $\mathbb{H}$ projector-plane of the line. Its traces are therefore AB_h and B_hB.

The traces of a plane containing EF and perpendicular to $\mathbb{V}$ are BA_v and A_vA.

104. The Line or Point on a Given Plane.—To determine whether a *line* lies on a given plane is a problem the reverse of that just treated. It amounts simply to determining whether the traces of the line lie on the traces on the plane. Thus, in Fig. 101, if PV and PH are given, and the line EF is given by its projections, the traces of EF must be found, and if they lie on PH and PV the line is then known to lie on the given plane P.

To determine whether a given *point* lies on a given plane is almost as simple. Join one projection of the point with any point on the corresponding trace of the plane. Find the other trace of the line so formed, and see whether it lies on the other trace of the given plane. Thus in Fig. 101, if the traces PH and PV and the projections of any one point, as E, are given, select some point on PH, as A, and join E_hA and E_vA_v. Find the trace B. If it lies on PV, the point E itself lies on P.

To draw on a given plane a line subject to some other condition, such as parallel to some plane of reference, is always a problem in constructing a line whose traces are on the traces of the given plane, and which yet obeys the second condition, whatever it may be.

105. The Plane Containing Two Given Lines.—From the last article, if a plane contains *two* given lines, the traces of the plane must contain the traces of the lines themselves. The given lines must be intersecting or parallel lines, or the solution is impossible.

In Fig. 102 two lines, AB and AC, are given by their projections. They intersect at A, since A_h, the intersection of the $\mathbb{H}$ projections,

is vertically above A_v, the intersection of the 𝕍 projections. Extend the lines to E, F, G and H, their traces on ℍ and 𝕍. Join the ℍ traces, E and G, and produce the line also to a on the axis of X. Join the 𝕍 traces, H and F, and extend the line HF also to a. Ea and aH are the traces of a plane P containing both lines, AB and AC. The meeting of the two traces at a is a test of the accuracy of the drawing.

This process may be applied to a pair of parallel lines, but not of course to two lines which pass at an angle without meeting.

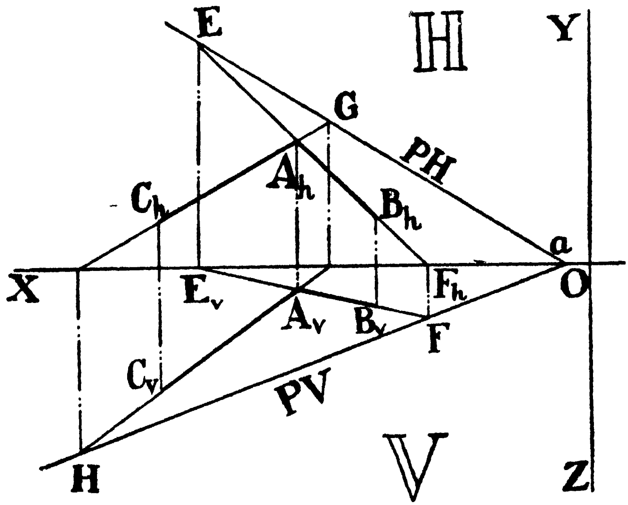


FIG. 102.

106. The Line of Intersection of Two Planes.—If two planes P and Q are given by their traces, their line of intersection must pass through the point where the ℍ traces meet and the point where the 𝕍 traces meet. Thus, in Fig. 103, PH and QH meet at A and PV and QV meet at B. A and B are points on the required line of intersection of P and Q, and since A is on ℍ and B is on 𝕍, they are the ℍ and 𝕍 traces of the line of intersection. AB_h and BA_v are therefore the projections, and should be marked PQ_h and PQ_v.

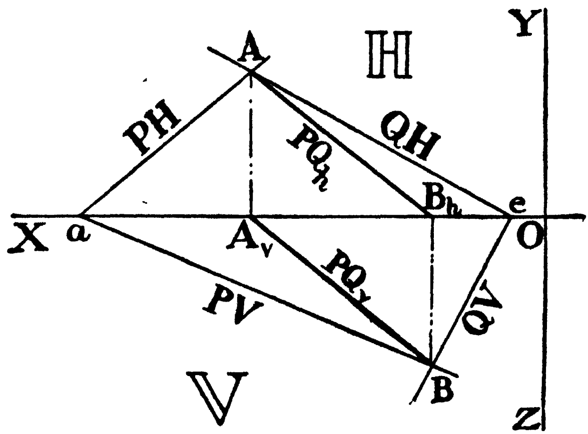


FIG. 103.

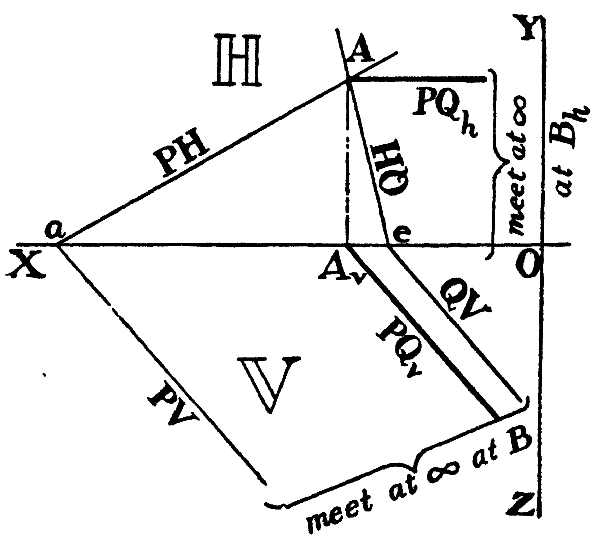


FIG. 104.

107. Special Case of the Intersection of Two Planes: Two Traces Parallel.—The construction must be varied a little in the special case when two of the traces of the planes are parallel. In Fig. 104 the traces PV and QV are parallel. In carrying out the construction as in Fig. 100, it is necessary to join A_v with B. But the point B is the intersection of PV and QV, which are parallel, and is therefore a point at an infinite distance in the direction of those lines, as indicated by the bracket on Fig. 104. To join A_v with B at infinity means to draw a line through A_v parallel to PV and QV.

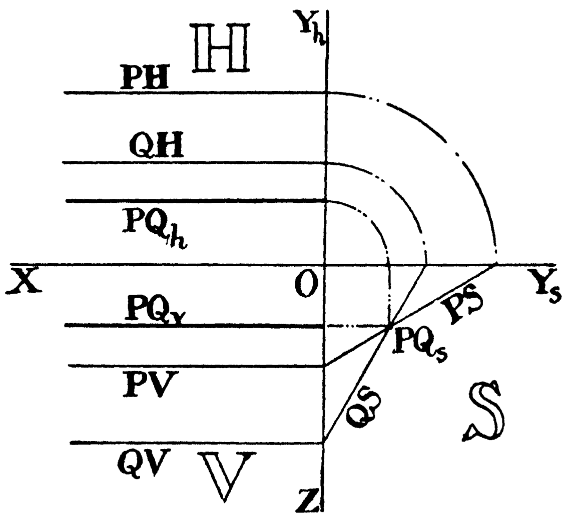


FIG. 105.

From B, at infinity, a perpendicular must be supposed to be drawn to the axis of X, intersecting it at B_h. B_h is therefore at an infinite distance to the right on the axis of X (extended). To join the point A with the point B_h means, therefore, to draw a line through A parallel to the axis of X. These lines are the required projections of PQ.

108. Special Case of the Intersection of Two Planes: Four Traces Parallel.—Another special case arises when the four traces (on two planes of projection) are parallel. It is then necessary to refer to a third plane of projection. In Fig. 105 the planes P and

Q have their four traces on ℍ and 𝕍 all parallel. The planes are inclined planes perpendicular to 𝕊, and if their traces are drawn on 𝕊, their intersection is the line PQ. In 𝕊 both P and Q are "seen on edge," so their line of intersection is "seen on end." From PQ_s, PQ_v and PQ_h are drawn by projection.

109. The Point of Intersection of a Line and a Plane.—The simple cases of this problem have been previously explained and used. If the plane is horizontal, vertical or inclined, there is

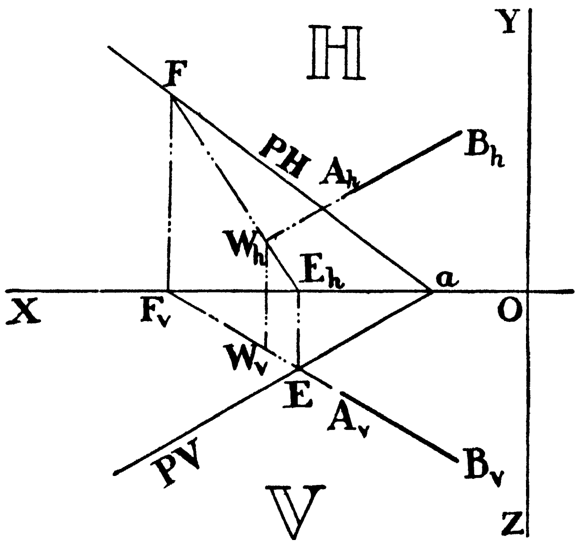


FIG. 106.

always one view at least in which it is seen on edge. In that view the given line is seen to pierce the given plane at a definite point from which, by the rules of projection, the other views of the point of intersection are easily determined. Thus in Fig. 27, Art. 38, the point a, where PA pierces the plane KL, is determined first in 𝕍 and then projected to ℍ and 𝕊.

The general case of this problem may be solved as in Fig. 106. A plane P is given by its traces PH and PV. A line AB is given by its projections. It is required to find where AB pierces P. The

solution is as follows: Let a plane perpendicular to V be passed through the projection A_vB_v. According to Art. 103 the traces of this plane are B_vF_v and F_vF. Draw the line of intersection of this plane with the plane P (Art. 106) as follows: B_vF_v and PV intersect at E. F and E are the traces of the line of intersection of the two planes. Complete the drawing of the line of intersection in H, as FE_h.

Referring to the horizontal projection, A_hB_h is seen to intersect FE_h, the H projection of the line of intersection, at W_h. Since both FE and AB are lines which lie in the vertical projector-plane through AB, this point of intersection, W_h, is the projection of the true point of intersection, W, of those two lines. From W_h project to W_v for the other projection of W. This point W which lies on P and is on the line AB is the required point.

Problems XI.

(For blackboard or cross-section paper or wire-mesh cage.)

110. Plot the point A (4, 7, 9). Pass a horizontal plane P through the point A, and draw the traces of P. Also a vertical plane Q, parallel to V, and draw its traces. Also an inclined plane R, perpendicular to H, making an angle of 45° with OX.

111. Plot the line A (8, 2, 4), B (2, 6, 16). Pass an inclined plane P perpendicular to H through this line and draw the traces of P. At C, the middle point of AB, pass a plane Q perpendicular to P and to H, and draw QH and QV.

112. The plane P cuts the axes at the points a (10, 0, 0), b (0, 5, 0) and c (0, 0, 15). Pass a plane Q parallel to P, through the point a' (6, 0, 0).

113. A plane P has its trace on H through the points A (12, 12, 0) and b (0, 6, 0). Its trace on V passes through the point c (0, 0, 12). Draw the three traces. Draw three traces of a plane Q, parallel to P through the point a' (3, 0, 0).

114. An indefinite line contains the points A (11, 2, 6) and B (5, 6, 0). Pass a plane P perpendicular to H containing this line and draw the traces PH, PV and PS. Pass a plane Q containing this line and the point a' (2, 0, 0). Draw the traces QH and QV. Draw the negative trace QS on S extended over H.

115. A plane P cuts the axis of X at a $(4, 0, 0)$, the axis of Y at b $(0, 6, 0)$, and the axis of Z at c $(0, 0, -12)$. Draw its traces. Draw the $\mathbb{V}$ and $\mathbb{S}$ traces of a plane Q parallel to P and containing the line A $(1, 4, 11)$, B $(4, 1, 14)$.

116. An inclined plane, perpendicular to $\mathbb{H}$, has for its $\mathbb{V}$ and $\mathbb{S}$ traces lines parallel to OZ at positive distances of 15 and 5 units. An inclined plane Q perpendicular to $\mathbb{H}$ has its $\mathbb{V}$ and $\mathbb{S}$ traces parallel to OZ at distances of 12 units and 8 units. Draw all three traces and the projections of PQ, their line of intersection.

117. Draw the traces of a plane P, containing the points A $(8, 1, 3)$, B $(4, 5, 1)$ and C $(2, 4, 3)$. Does the point D $(4, 1, 5)$ lie on this plane?

118. The traces of a plane P are lines through the points a $(10, 0, 0)$, b $(0, 15, 0)$ and E $(14, 0, 6)$. A plane Q has its traces through the points a' $(2, 0, 0)$, E, and F $(7, 5, 0)$. Draw the projections of their line of intersection, PQ.

119. The plane P cuts the axes at a $(12, 0, 0)$, b $(0, 12, 0)$ and c $(0, 0, 12)$. Where does the line K $(1, 5, 12)$, L $(5, 3, 6)$ pierce the plane?

CHAPTER XII.

VARIOUS APPLICATIONS.

110. Traces of an Inclined Plane Perpendicular to an Oblique Plane.—One of the most general devices used in the drafting room is the auxiliary plane of projection, and it is often advantageous to pass this plane perpendicular to some plane of the drawing in

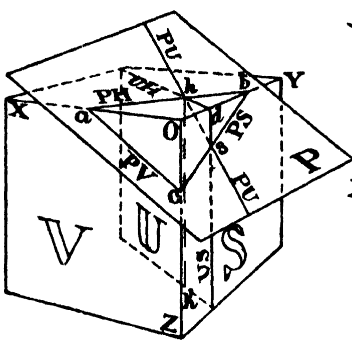


FIG. 107.

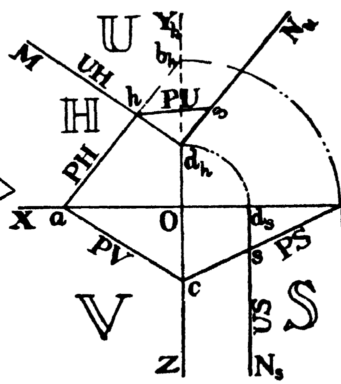


FIG. 108.

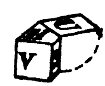


FIG. 109.

order to get the advantage of showing that plane "on edge." Thus in Fig. 32, Art. 44, the plane 𝕌 has been taken perpendicular to the long rectangular faces of the triangular prism, in order to show clearly where BB' and DD' pierce those planes. The manner of passing the plane 𝕌 was fairly clear in that case from the simplicity of the figure. However, as it is not always clear how to pass a plane perpendicular to an oblique plane, the general method may well be explained here. In Fig. 107 the plane P, previously shown in Fig. 94, is represented, and an auxiliary plane 𝕌, perpendicular to it and to ℍ, is shown. The traces of P are PH, PV and PS as before, and the traces of 𝕌 are UH and US. It must

be understood that the H traces of these planes, PH and UH, are *perpendicular to each other*, as this condition is essential if P and U are to be planes perpendicular to each other.

Fig. 108 is the descriptive drawing corresponding to the perspective drawing, Fig. 107. At some point h on PH a line Md_h has been drawn perpendicular to PH. This line is the inclined trace of a plane U perpendicular to H. The other traces of U are parallel to the axis of Z (Art. 98). One of these, the trace on S, is shown by the line d_sN_s, parallel to OZ, d_h and d_s being two representations of the same point d in Fig. 107, just as b_h and b_s represent the point b, duplicated. Md_h may be called UH and d_sN_s may be called US. UH and US are the traces of an inclined plane U, perpendicular to the oblique plane P.

The proof that P and U are perpendicular to each other is as follows: If, in Fig. 107, a line hh' is drawn perpendicular to H at the point h, it will lie in the plane U. The angle ahh' will then be an angle of 90°, and by construction the angle ahd is also 90°. Thus the line ah is perpendicular to two intersecting lines described in the plane U and is therefore perpendicular to U itself. The plane P contains the line PH and is thus perpendicular to U.

111. An Auxiliary Plane of Projection Perpendicular to an Oblique Plane.—To utilize the inclined plane U as an auxiliary plane of projection, its developed position must be shown by drawing d_hN_u perpendicular to UH. This line is the duplicate position of d_sN_s or US. In developing the planes, U is first revolved on UH as an axis into the plane of H as shown in Fig. 109, and then with H into the plane of the paper, V. The trace of P on U, or PU, is the line of intersection of the planes, and is shown clearly in Fig. 107. This line passes through h where PH and UH meet, and through s where PS and US meet. In Fig. 108, d_hs is laid off on d_hN_u, equal to d_ss, and the line hs is the required trace of P on U, or PU. The actual line PU, in Fig. 108, is only that part of PU, in Fig. 107, which is between h and s, shown as a broken line.

The important part in this process is that U is taken perpendicular to P, so that P is "seen on edge" on U. By this process the plane P, which is *oblique* when H, V and S are considered,

becomes an *inclined* plane when only 𝕳 and 𝕌 are considered. As it is easier to deal with inclined than with oblique planes, we

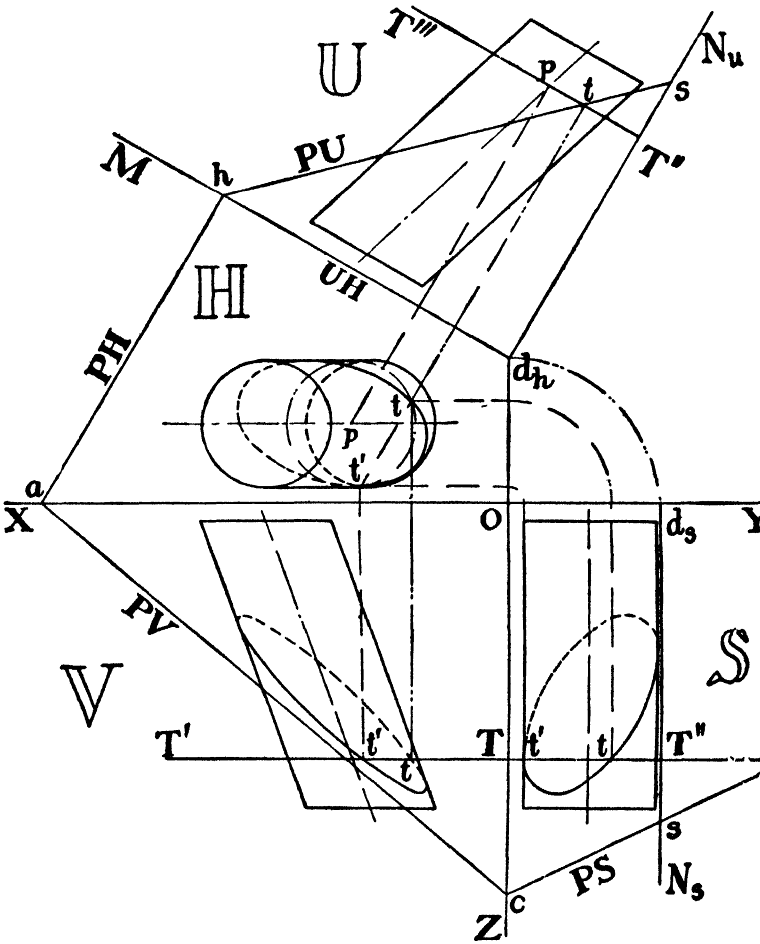


FIG. 110.

may now treat *P* as inclined to 𝕳 and perpendicular to 𝕌 in further operations.

Fig. 108 is well adapted to making a paper box diagram which,

when folded, will give most of the lines of Fig. 107. To reconstruct Fig. 108, plot the points a (18, 0, 0), b (0, 18, 0), c (0, 12, 0), d (0, 6, 0), h (6, 12, 0) and s (0, 6, 8). The line d_hN_u is at an angle of 45° with ZOY_h and the construction space $Y_sOd_hN_u$ can be folded away inside by creasing or cutting it on several lines.

112. Intersection of an Oblique Plane and a Cylinder.—An example of the use of an auxiliary view on which an oblique plane is seen on edge is shown in Fig. 110. An inclined cylinder is intersected by an oblique plane P given by its traces PH, PV and PS. It is required to describe on the cylinder the curve of intersection of the plane and the cylinder. The solution is as follows: An auxiliary plane $\mathbb{U}$, perpendicular to P and to $\mathbb{H}$, is chosen, and PU is drawn upon $\mathbb{U}$ as in Fig. 108. PU is the view of P "seen on edge" in $\mathbb{U}$. Auxiliary cutting planes parallel to $\mathbb{H}$ are used for the determination of the required line of intersection. The traces of one of the planes are drawn, as $T'T$ in $\mathbb{V}$, TT'' in $\mathbb{S}$, and $T''T'''$ in $\mathbb{U}$. This latter trace is parallel to d_hM (or UH), because T is parallel to $\mathbb{H}$, and the distance d_hT'' is equal to d_sT'' in $\mathbb{S}$. $T''T'''$ cuts the axis of the cylinder at p. p is projected to $\mathbb{H}$, and the circular element described in $\mathbb{H}$, with p as a center, is the intersection of the auxiliary plane T and the cylinder. In $\mathbb{U}$ the planes P and T are both "seen on edge," intersecting in a line "seen on end." This point projected to $\mathbb{H}$ gives this line of intersection of P and T as tt'.

The intersections of the intersections are therefore the points t and t', where the circle and the straight line meet.

113. The Angle between Two Oblique Lines.—This problem of finding the angle between two oblique lines is shown in Fig. 111. Let two lines AB and AC, meeting at A, be given by their $\mathbb{H}$ and $\mathbb{V}$ projections. It is required to find the true angle between them.

By the process of Art. 105, Fig. 102, the traces of the plane containing AB and AC are found and the lines are all lettered according to Fig. 102.

An auxiliary plane of projection, $\mathbb{U}$, is passed perpendicular to PV, and therefore perpendicular to both P and $\mathbb{V}$, and is revolved into the plane $\mathbb{V}$. The projections of AB and AC on this plane

fall in the single line $A_uC_uB_u$, since P, the plane of the lines, is "seen on edge" on $\mathbb{U}$. A portion of the plane P is now revolved about the $\mathbb{U}$ projector of the point A into a position parallel to XM. In $\mathbb{U}$, C_u moves to C'_u and B_u to B'_u, revolving about A as their center. In $\mathbb{V}$, B_v moves to B'_v and C_v to C'_v, both parallel to XM. This is the process of finding the true length of a line by revolving about a projector, as in Art. 32. $A_vB'_v$ is the true length

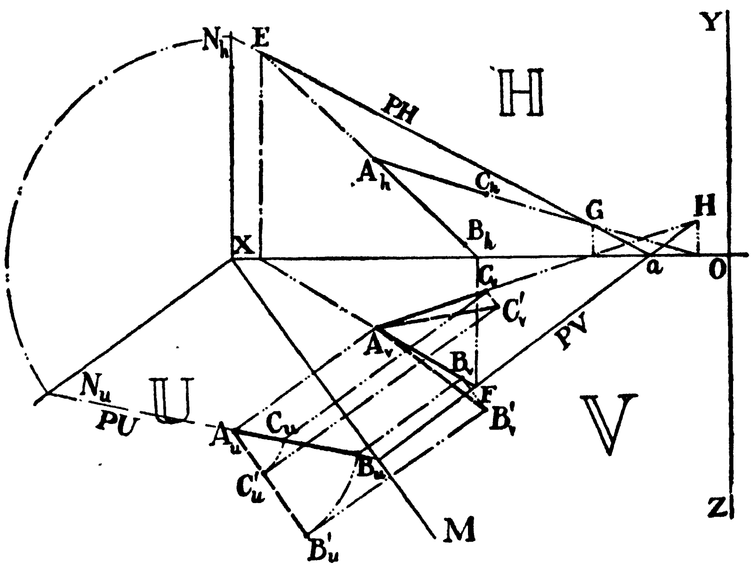


FIG. 111.

of AB; $A_vC'_v$ is the true length of AC; and $B'_vA_vC'_v$ is the true angle between the lines.

This process makes it possible to find the *true shape* of any figure described on an oblique plane.

114. A Plane Perpendicular to an Inclined Line.—It is often advantageous to pass a plane perpendicular to a line in order to use the plane as a plane of projection, on which the given line will be seen on end as a point. The method of passing a plane perpendicular to an inclined line is shown in Fig. 112. Let AB be an inclined line, lying in a plane parallel to $\mathbb{V}$, so that A_hB_h is parallel

to the axis of X. It is required to find the traces of a plane P perpendicular to AB. The essential point is that the traces of the plane must be perpendicular to the corresponding projections of the line. Thus, choose some point p on the inclined projection of the line, in this case on A_vB_v, and through p draw a perpendicular to A_vB_v, to serve as the trace of P. At a, where this trace PV

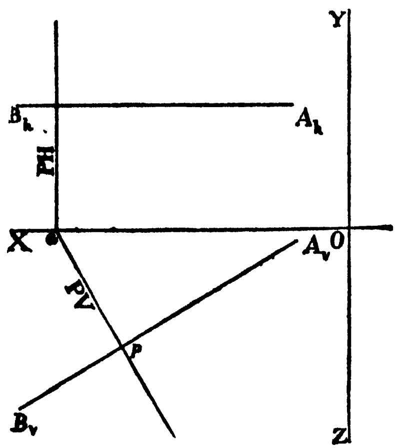


FIG. 112.

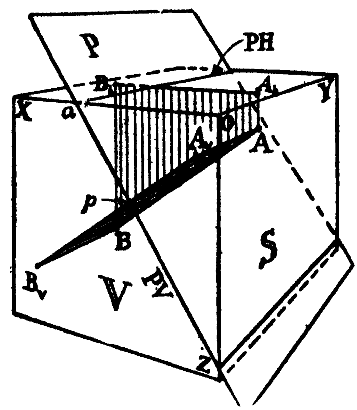


FIG. 112-B (Perspective).

meets the axis of X, erect a perpendicular to PH. These lines PV and PH are the traces of an inclined plane perpendicular to AB and to V. It is noticeable that the inclined trace of the plane is on that reference plane which shows the inclined projection of the line.*

---

* A proof that P is perpendicular to AB is as follows: AB is the line of intersection of its own H projector-plane, and its own V projector-plane. P is perpendicular to both these projector-planes. For, P is perpendicular to V and therefore to the H projector-plane, which is parallel to V; the V projector-plane is perpendicular to V, so that it is seen on edge on V just as is P itself; apA_v is therefore the true angle between these two planes, and by construction is a right angle. P is therefore perpendicular to both projector-planes and therefore to the line AB, which is their line of intersection.

115. Application of a Plane Perpendicular to a Line.—In Fig. 113 an application of an inclined plane perpendicular to an inclined line is made for the purpose of finding the line of intersection between an inclined cone and an inclined cylinder whose axes do not meet.

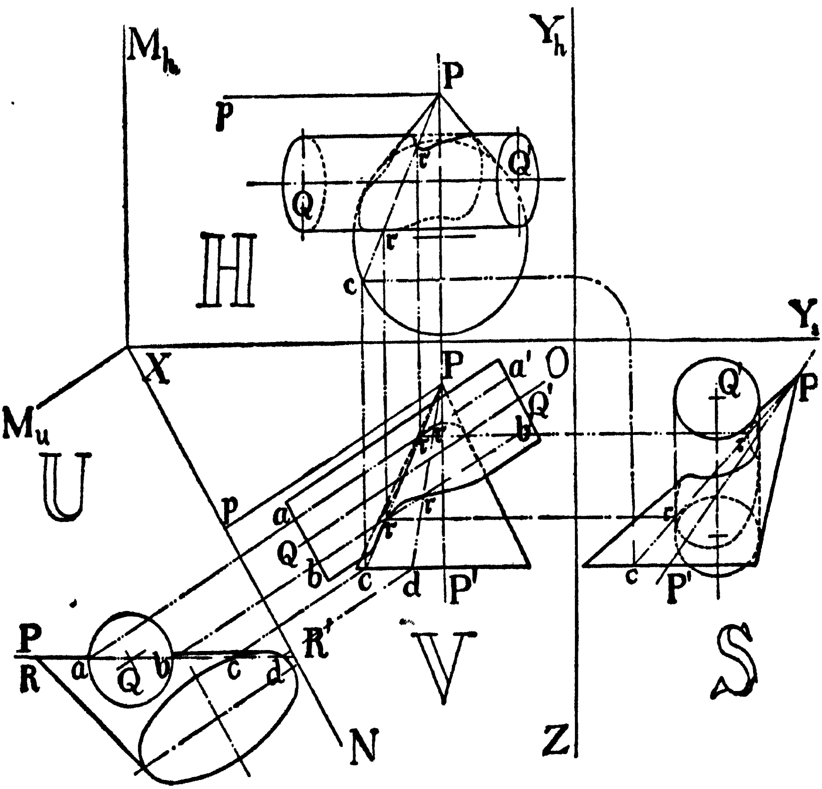


FIG. 113.

If from P, the vertex of the cone, a line Pp is drawn parallel to QQ', as shown, any plane which contains this line and cuts both surfaces will cut only simple elements of the surfaces. For such a plane contains the vertex of the cone, and therefore, if it cuts the cone, will cut it in *straight* elements; and such a plane is parallel to QQ' and therefore, if it cuts the cylinder, cuts only straight elements. No other planes can be found which cut simple elements and can be used to determine the line of intersection.

If a plane $\mathbb{U}$ is passed perpendicular to Pp at any point p, and is used as an auxiliary plane of projection, Pp will be seen on end as the point P, and any plane R through P seen on edge in $\mathbb{U}$, as RR', will cut only straight elements on the two curved surfaces. The complete projections of the cone and cylinder have been shown on $\mathbb{U}$, and the plane R cuts the bases at a, b, c and d. These points projected to $\mathbb{V}$ enable the elements to be drawn there, and the intersections of the intersections are the four points marked r. From $\mathbb{V}$ these points are projected to $\mathbb{H}$ and $\mathbb{S}$. Two of these

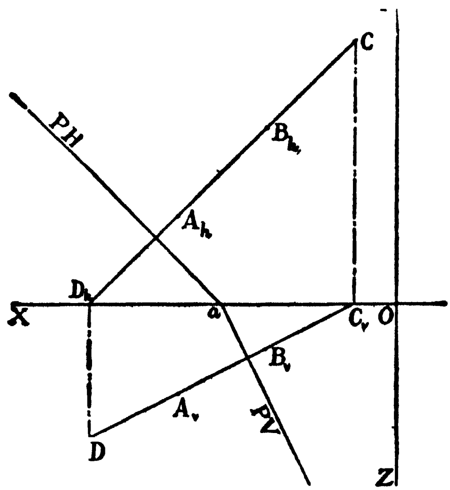


FIG. 114.

points r have been projected to the other views to show the necessary construction lines.

116. A Plane Perpendicular to an Oblique Line.—To pass a plane perpendicular to an oblique line, it is only necessary to draw the traces of the plane perpendicular to the corresponding projections of the line. In Fig. 114, let AB be an oblique line. At any point on A_hB_h draw a perpendicular line PH. From a, where PH meets the axis of X, draw PV perpendicular to AB.*

* The proof of this construction is more difficult than in the corresponding case of an inclined line, but it depends as before on the line AB being the intersection of its $\mathbb{H}$ and $\mathbb{V}$ projector-planes, and these planes themselves being perpendicular to P.

A paper box diagram traced from Fig. 114, or constructed on coordinate paper, using the coordinates A (10, 4, 4) and B (6, 8, 2), C (2, 12, 0) and D (14, 0, 6) and a (8, 0, 0), will assist materially in understanding the problem.

The oblique plane P is not serviceable as an auxiliary plane of projection.

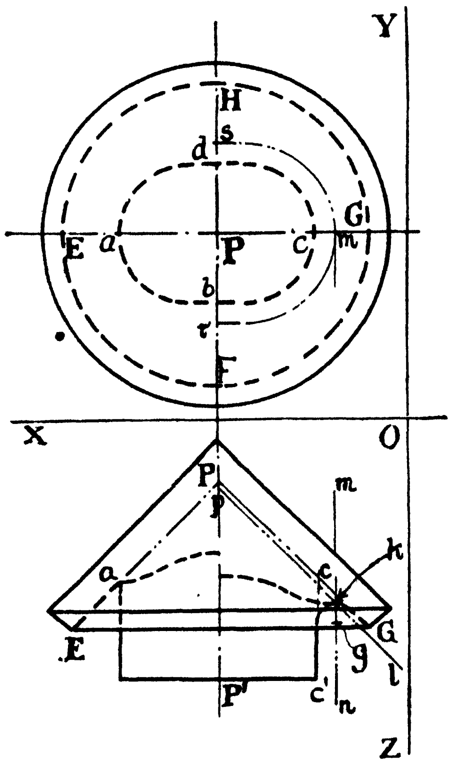


FIG. 115.

117. Alteration of a Curve of Intersection by a Fillet.—In Fig. 115 a hollow cone and a non-circular cylinder, *abcd* in [H], intersect. On the left half the unmodified curve of intersection is traced by the method of the Art. 85, p. 309, no construction lines being shown however, as the case is very simple. On the right half the curve is modified by a fillet or small arc of a circle which fills in

the angular groove. The fillet whose center is at g modifies that point of the line of intersection marked c. The top of the circular arc marks the point where a $\mathbb{V}$ or $\mathbb{S}$ projector is tangent to the surface.

The corresponding crest to the fillet at other positions on the curve of intersection is traced as follows: If a line drawn through k and parallel to PG, the generating line of the cone, is used as a new generator it will by its rotation about PP' create a new cone, on the surface of which the required line of the crests of the fillets must lie. If a line mn, parallel to cc', the generating line of the cylinder, is moved parallel to cc', and at a constant distance from the surface of the non-circular cylinder, it will generate a new non-circular cylinder on the surface of which the required path of the point k must lie. The directrix of this new cylinder is drawn in $\mathbb{H}$, the line rms, as shown. The intersection of these two new surfaces, solved by Solution No. 1, or Solution No. 4, is the required path of k, which must be traced on $\mathbb{V}$ and $\mathbb{S}'$.

Castings commonly have sharp interior corners modified by a fillet. This alteration must be resorted to if the line of the crest of the fillet must be accurately shown. This, however, is not always the case, and, in practice, such a line is often put in by guess from its critical points which are easily found.

118. The Application of Axes of Projection to Mechanical Drawings.—Descriptive Geometry is a geometrical science, the science dealing primarily with orthographic projection, while Mechanical or Engineering Drawing is the art of applying these principles to the needs of engineers and mechanics in the pursuit of industries. Engineering Drawing includes therefore many abbreviations and conventional representations, which seek to curtail unnecessary work and often to convey information as to methods of manufacture and other such commercial considerations foreign to the strict scientific study. It forms the subject of the third part of this text-book.

At first sight, because axes of projection are not used, one may think that engineering drawing is free of the shackles of the system of coordinates. As a fact, distances are as accurately laid off from center lines in practise, as they are in descriptive geometry from

axes. The next chapter of this work shows how to insert axes in engineering drawings, if needed, and how to use the center lines as substitutes for general service.

119. Practical Application of Descriptive Geometry.—Many draftsmen have picked up a knowledge of Descriptive Geometry without direct study of the science. This is largely due to the fact that, till very recently, all books on Descriptive Geometry were based on a system of planes of projection which are analogous to the methods of practical drawing in use on the continent of Europe, but which are little used in England, and hardly at all in the United States of America. It will be found, however, that in American drafting rooms all the usual devices of draftsmen are applications, sometimes almost unconscious applications, of the principles covered in the preceding chapters. The favorite device is the application of an inclined auxiliary plane of projection, suitably chosen; next in importance is the rotation of the object to show some true shape; while other applications are used less frequently. The methods of determining lines of intersection of planes and curved surfaces are exactly those described in Chapters III, IV and VI.

In fact it has been our aim to dwell on methods which have applications in practical drawing and our examples have been chosen, as much as possible, from actual mechanical objects.

Problems XII.

(For use on blackboard, with cross-section paper or wire-mesh cage.)

120. The plane P has its traces through the points a (14, 0, 0), b (0, 14, 0) and c (0. J. 7). Pass a plane Q, perpendicular to P and to $\mathbb{H}$, through the point A (5, 7 0). If Q is to be used as an auxiliary plane of projection, draw the trace of P on Q when Q has been revolved into coincidence with $\mathbb{H}$.

121. Draw the traces of a plane P cutting the axes at the points a (12, 0, 0), b (0, 8, 0) and c (0, 0, 12). Draw the traces of an auxiliary plane, $\mathbb{U}$, perpendicular to PH at the point A (3, 6, 0). Is the point B (6, 1, $4\frac{1}{2}$) on the plane P?

122. The $\mathbb{H}$ trace of a plane P passes through the points A (12, 5, 0) and B (6, 2, 0). Its $\mathbb{V}$ trace passes through C (9, 0, 6).

Pass an inclined plane perpendicular to H and perpendicular to P, through the point D (5, 9, 7).

123. Of a plane P, PH, the horizontal trace, passes through the points A (5, 3, 0) and B (13, 9, 0), and PV passes through C (12, 0, 11). Complete the traces of P and draw the traces of a plane perpendicular to PV at the point D (9, 0, 8). Prove that the line E (10, 6, 1), F (7, 3, 2) lies on the plane P.

124. A sphere of radius 7 units has its center at C (8, 8, 8). A plane P cuts the axes of projection at a (26, 0, 0), b (0, 13, 0) and c (0, 0, 13). Pass an auxiliary plane of projection U, perpendicular to H andto P, cutting the axis of X at d (16, 0, 0). Draw the trace of P on U. The circle of intersection of the sphere and the plane P is seen on edge in U. Show the elliptical projection of this rircle, on H, by passing auxiliary cutting planes parallel to U. (If this problem is solved by use of wire-mesh cage, the point a is inaccessible, but PH passes through E (16, 5, 0), and PV through F (16, 0, 5). The plane S′ can be turned to serve as U.)

125. Find the true shape of the triangle A (3,2 6), B (9, 6, 2), C (8, 0, 4). Find the traces of two of the sides of the triangle and pass the plane U perpendicular to the plane of the triangle and perpendicular to H, and through the point D (0, 7, 0).

126. Find the true shape of the triangle A (8, 6, 1), B (4, 2, 9), C (10, 2, 3). Find the traces of two of the sides of the triangle and pass the plane U perpendicular to the plane of the triangle and perpendicular to H, and through the point D (0, 1, 0).

127. Draw the traces of a plane P perpendicular to V and to the line A (2, 6, 9), B (8, 6, 5) at C (11, 6, 3). If this plane is used as an auxiliary plane of projection, what is the projection of AB on it?

128. Draw the traces of a plane P perpendicular to H and to the line A (3, 9, 6), B (13, 4, 6), at C (17, 2, 6), a point on AB. (If wire-mesh cage is used for the solution, turn S′ to serve as U and draw on it the view of A_uB_u.)

129. Draw the three traces of a plane P perpendicular to the oblique line A (8, 12, 5), B (14, 3, 7). Show that all three traces are perpendicular to the corresponding projections of AB.

Sheets 21 to 24, pages 383 and 384, complete the subject.

CHAPTER XIII

DESCRIPTIVE GEOMETRY WITHOUT AXES

120. Orthographic Projection without Axes.—Until now axes of projection have been used in connection with coordinates, so that each point on the drawing should be exactly located. By their use the relation between the three customary views of a given point was reduced to three laws of projection, Art. 11, and by applying these laws to all the points of a solid object we obtained a clear idea of the exact relation of each view of the object to its neighbors.

We wish now to pass to the use of orthographic projections, usually three in number, without the use of axes of projection, since these are not customary in practical drawings. Planes of projection, $\mathbb{H}$, $\mathbb{V}$, and $\mathbb{S}$, are used as before, and the existence of axes of projection is *implied*. We may fall back upon their use whenever the lack of them is felt. The absence of the axes does not prevent the exact observance of the laws of projection, although the manner of carrying out the third law is somewhat modified.

121. Restatement of the Laws of Projection.—The three laws of projection were originally stated for a single point, and with reference to the most usual method of developing the projections on $\mathbb{H}$, $\mathbb{V}$, and $\mathbb{S}$, that in which $\mathbb{S}$ is to the right of $\mathbb{V}$ as in Fig. 116, p. 350. In practical drawing it is almost as common to have $\mathbb{S}$ to the right of $\mathbb{H}$, or to the left of $\mathbb{V}$, or of $\mathbb{H}$. In all four of these possible arrangements there is one view to which both the others are imagined to be hinged, so that they may be swung into coincidence with it. In the arrangement we have considered the standard one, $\mathbb{V}$ is this plane, and we may well say that the projection on it is the *central view*, and that the other two are *outlying views*.

Using this nomenclature, which will cover any arrangement of views. we may state the rules of projection more broadly thus:

(1) From the central view points project vertically to one of the outlying views.

(2) From the central view points project horizontally to the second outlying view.

(3) Vertical dimensions on the first outlying view must check with horizontal dimensions on the second outlying view.

In this wording, "vertical" and "horizontal" refer to the north-and-south and east-and-west directions on the drawing paper, not to the dimensions of the object itself as imagined in space.

As applied to Fig. 116, in which V is the central view, we see that points on V project vertically (up) to H, the first outlying view,

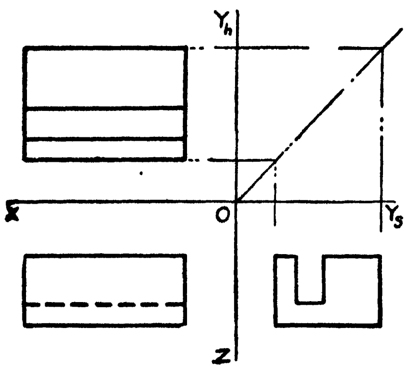


FIG. 116.

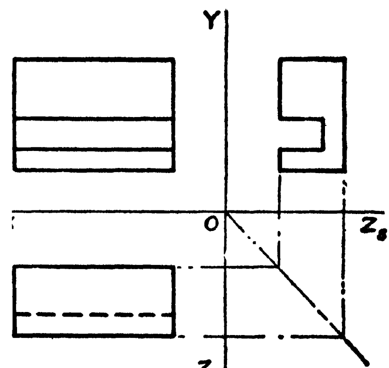


FIG. 117.

and horizontally to S, the second outlying view. We see also that vertical dimensions of the object on H reappear as horizontal dimensions on S, as indicated by the construction lines which connect the extreme edges.

As applied to Fig. 117, H is the central view, which projects vertically (down) to V, and horizontally to S. Vertical dimensions of the object on V reappear as horizontal ones on S, as indicated by the lines connecting the views.

122. Projection of Points between Outlying Views without Axes.—It will be noticed that in Figs. 116 and 117, one could erase the coordinate axes, choose a new point on the 45° line (extended to the left of the present origin if desired), and, using it as origin, put in

new axes of projection. The projection of points from view to view would not be disturbed.

It is evident, then, that in practice we may discard the axes entirely and keep only the 45° line, and still have the means for easy projection of points from one outlying view to the other. In Figs. 118 and 119 this step has been taken. These are practical drawings, without axes, but with the 45° line. In Fig. 118, the horizontal center line of the plan and the vertical center line of the side elevation have been produced until they meet on the 45° line at *a*, and at *b* there is an indication of the projection of the bottom edge of the plan to form the left edge of the side view. Of course, any number

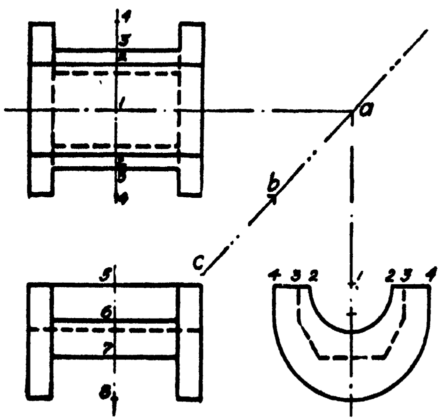


FIG. 118.

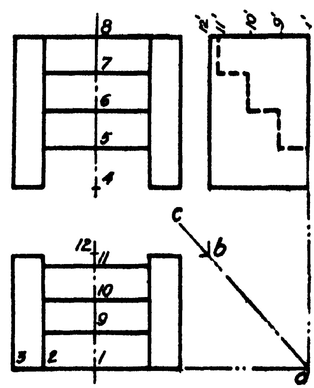


FIG. 119.

of points may be so connected in the two views. In Fig. 119, the bottom plane of the front elevation has been extended to the 45° line at *a*, and thence to the side elevation to form its right edge.

123. How to Find the 45° Line.—If a practical drawing (such as Fig. 118 with the line *cba* omitted) is provided, and it is required to supply it with coordinate axes, the first step is to locate the 45° line. This is accomplished by choosing some plane of the object *which is parallel to the plane of the central view.* In Fig. 118 the two center lines which are joined at *a* really represent a plane parallel to V, and these lines are the traces of that plane on H and S. This plane is a plane of symmetry, a plane which divides the object

into two equal halves. Whenever the two outlying views have center lines, which represent a plane of symmetry parallel to the plane of the central view, these lines may be extended until they meet and their intersection will establish a point on the 45° line.

In Fig. 119 (repeated on the opposite page), there is no plane of symmetry parallel to H. The plan is the central view. The base line of the front elevation and the right edge of the side elevation represent a plane surface of the object parallel to H, the plane of the central view. These lines, extended until they meet at *a*, fix the position of the 45° line.

124. Choice of Origin for Axes of Projection.— We have just shown that the actual axes are unnecessary if the 45° line is located. This is true for all but the most difficult operations in descriptive geometry.

In theory, any point on the 45° line may be used as origin. In practice, a point should be chosen near the central view. Thus in Fig. 118, opposite, any point between *b* and *c*, when used as origin, will cause all points of the object to have only positive coordinates. In Fig. 119, any point on the part of the 45° line above *b* will serve.

125. Plotting from Center Lines and Base Lines.—The use of the 45° line is the step midway between the use of axes of projection and the entire suppression of them. It is also the middle step in inserting axes in a drawing without them. We wish, however, to be able to ignore axes entirely and to fall back upon them only when some knotty problem makes it advisable to do so.

Drawings are usually constructed with no axes and no 45° line. Agreement of dimensions between the views is secured by projection and by the duplication of dimensions by use of dividers, bow spacer and bow pencil.

For example, let us imagine ourselves drawing Fig. 119, in the six steps for pencilling shown on page 118. In the first step the center lines would be drawn and probably the bottom line of the front elevation and right edge of the side elevation as a base line. On these, various dimensions would be pointed off. The *x* dimensions of the piece might be laid off either on plan or on front elevation. Probably from point 1, points 2 and 3 would be laid off and then duplicated to the right of the center line by dividers. These points

plotted, the corresponding lines in the plan would be obtained by projection from them, in the process of squaring out. In the same way points 4, 5, 6, 7, and 8 would be laid off on the plan, and in squaring out projected to the side view. These are the y dimensions of the object.

The z dimensions are vertical in the front view and horizontal in the side view. To make them agree they should be laid off in the one place and transferred to the other by dividers. Thus the points 9, 10, 11, and 12 might be pointed off from 1 on the front view, and the same set of distances transferred to the side view, as 1′, 9′, 10′, 11′, and 12′. The figure is then squared out.

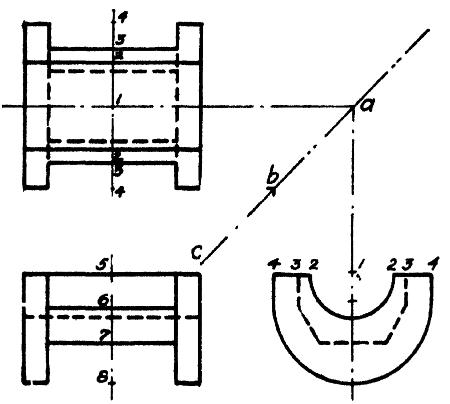


FIG. 118.—Repeated.

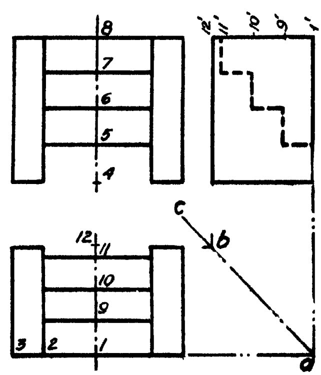


FIG. 119.—Repeated.

In Fig. 118, dimensions marked by points 1, 2, 3, and 4 appear on each side of the center line in each of the outlying views. The distance 1-3 would be taken from the scale by the dividers and plotted in all four places. The distance 1-2 is a dimension of a "chief circle." The compass or bow pencil is set to it and the semicircle in the side view described. Immediately the needle is transferred to 1 in the plan and two faint arcs of circles described, locating the two points 2 on the plan. In this way the proper projection between outlying views is secured as we proceed.

126. Auxiliary Views.—To get the true shape of some inclined face we often found it necessary to employ auxiliary planes of pro-

jection. These auxiliary views are very common in practical drawing, in order to show the true shape of some feature of the object set at an angle. It is common to limit such auxiliary views to the one feature alone and not to project the rest of the object, as it would be an oblique view of it. Thus in Fig. 120, a Y-pipe is shown with flanged ends. There is a plan, a front view and an auxiliary view at an angle to show the true shape of the flange on the 60° branch, including its bolt holes. Note that the auxiliary view is

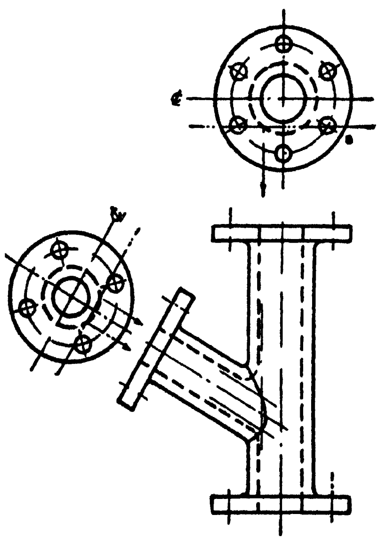


FIG. 120.

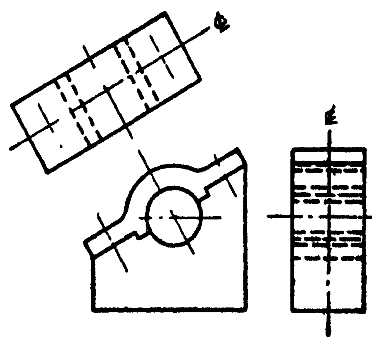


FIG. 121.

incomplete, showing the flange only, as is also the plan. To complete either one involves projecting circles as ellipses, a tedious task, which should always be avoided if there is no proof of a real necessity for undertaking it.

This drawing illustrates the application of descriptive geometry to drawings without axes, by means of the dividers. The horizontal center line of the plan and the SW-NE center line of the auxiliary view, those marked with *CL* in form of a monogram, are traces of a plane of symmetry. To find points on the line of intersection of the two cylinders, a plane parallel to it may be passed, as shown by

the construction lines, which are at the same distance from the center lines in both views. In practical drawings, this line of intersection is often advisable, even when the parts are filleted so that no sharp edge remains.

In Fig. 121 a journal bearing is shown. The views are, a front view, a side view, and a partial auxiliary view, to show the true shape of the "cap."

The vertical center line of the side view and the SW-NE center line of the auxiliary view are traces of the same plane of symmetry. Therefore distances perpendicular to them are alike in both views. The dividers are used in securing this agreement.

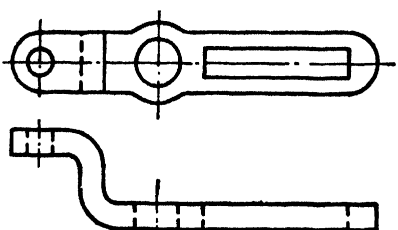


FIG. 122.

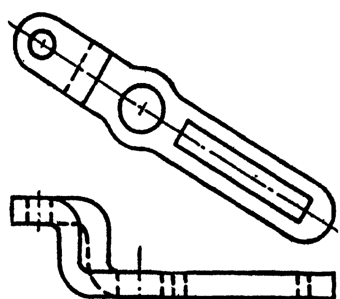


FIG. 123.

127. Oblique Views, or "Oblique Projections."—These terms are used to describe an orthographic projection upon a plane inclined to the natural plane faces of the object. There is another meaning to the term "oblique projection," a form of projection which is not orthographic at all, so the term "oblique view" is better.

The aim in practical drawing is to avoid, as far as possible, all oblique views. For this reason the partial projections in Figs. 120 and 121 were left incomplete. It may happen, however, that some important reason necessitates an oblique view. For example, the bent lever in Fig. 122, when drawn alone, would always be placed in some horizontal or vertical position, giving the pair of views there shown. As a part of a complete mechanism of many pieces, to make it fall clear of some other portion of the drawing, the lever may be drawn to advantage in an angular position, necessitating one

oblique view. If we turn the plan through an angle of 30°, for example, an oblique view takes the place of the front elevation. Need for this will be seen later.

The formation of oblique views from the rectangular views is a useful test of understanding of the principles of projection.

128. Intersections of Solids Having Plane Faces.—The method employed in Chapter IV involves tracing the *edges* of one solid and finding where they pierced the *plane faces* of the other. Only after this has been done for both solids in turn are the *points*, so located, joined to produce the *lines* of intersection. To do this we must have views on which the planes under consideration appear

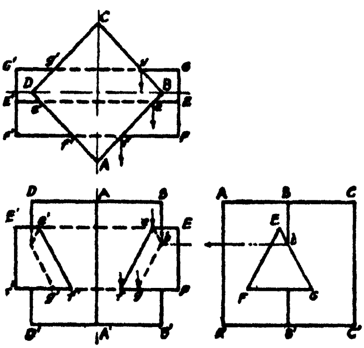


FIG. 124.

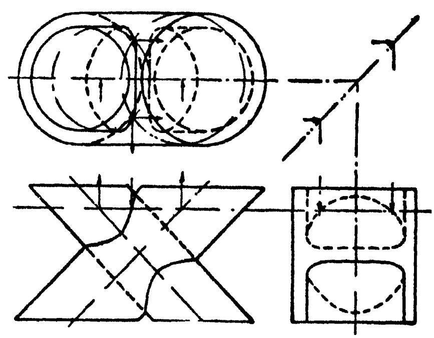


FIG. 125.

"on edge," and if such views are absent, auxiliary views must be constructed, at least in part, for that express purpose.

Fig. 124 illustrates a simple case worked out for a drawing without axes. In this case the plan and side views show the planes, which intersect, "on edge," and no auxiliary views are needed. A system of lettering points, such as that shown, is almost a *sine qua non* for this kind of work. Without it one easily becomes confused.

129. Intersections of Curved Surfaces.—The method taught in Chapters VI to VIII involves the use of auxiliary cutting planes so chosen as to cut straight or circular elements of the curved surfaces. It is necessary to pass one cutting plane at a time, to trace its lines of intersection with each surface, and to find the

intersection of the intersections. We thus arrive at points on the curve of intersection.

This process can be carried out without axes of projection. In Fig. 120, the construction for cutting planes paralled to V is shown. In Fig. 125, an example is worked out with the aid of a 45° line. Two inclined circular cylinders intersect, the smaller piercing the larger. Here cutting planes, parallel to H, have been selected. Such a plane cuts each surface in circular elements. The circles appear on edge as straight lines on front and side views, but as true circles on the plan, their centers marked by arrows which have been projected up from V. The circles on H intersect and arrows show how the points of intersection are projected to V and S.

Another solution is by planes parallel to V. Such planes cut each cylinder in straight elements.

In the general case, if planes parallel to H, V and S have been examined to see if they cut simple elements with *both* surfaces, elements which will appear on the drawing as straight lines or circles, and each in turn has failed to give the required simple intersections, one must then try the passing of planes perpendicular to one of the regular planes of projection, **containing the vertex, or the axis,** of the cylinder or cone in question. Auxiliary cutting spheres are occasionally useful for surfaces of revolution whose axes intersect.

If all these seven possible solutions fail, construct an auxiliary view on a U plane and try for a solution by cutting planes perpendicular to U.

130. Review of Principal Features of Descriptive Geometry.— This chapter, while primarily showing the use of orthographic projection without axes, has in its process reviewed the Laws of Projection, the Auxiliary view on a U plane, and the Intersections of prisms, pyramids, cylinders and cones.

A review of the current subject is always valuable on the eve of starting a new one. In this case we start the practical subject of Engineering Drawing, Part III of this textbook, after having made a sufficient number of descriptive drawings based on the matter of Chapter XIV, or similar material, to fix the subject properly in the mind.

Problems XIII.

(These problems may be transferred to cross-section paper for solution.)

130. Fig. 126 represents a grindstone. Plan and side elevation are shown. Form the oblique view to the right of the side view at an angle of 45°, the center line shown serving as the trace of the plane of symmetry represented by the vertical center line of the plan.

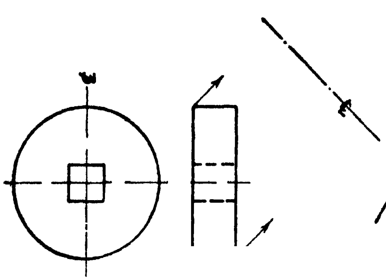


FIG. 126.

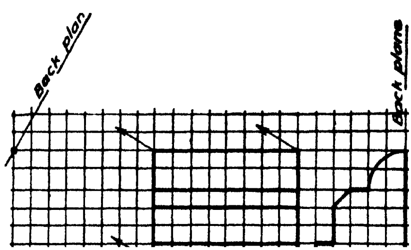


FIG. 127.

131. Fig. 127 represents a piece of wooden molding. The drawings are a front elevation and a side elevation. Draw the oblique view to the left at an angle of 30°, using the base line, already drawn, to represent the back plane of the molding.

132. Fig. 128 represents two prisms intersecting. Finish the drawing to represent the triangular prism as piercing the square one. The first step is to draw the plan of the triangular prism. It will be necessary to locate on the auxiliary view, which shows the triangular prism on end, the line AA' before the intersection can be plotted on the other views, A being the point of the square, in the plan, nearest to the front. The rest of the auxiliary view does not aid in completing the regular views and should not be completed.

133. In Fig. 129 pass one or two cutting planes parallel to V, and show how the intersection may be worked out. The problem is similar to the one illustrated by Fig. 125 on page 356. Cutting planes paralleled to H, or to V, may be used.

134. In Fig. 125 the two circular cylinders have their axes inclined at angles of 45°. They intersect at their middle points.

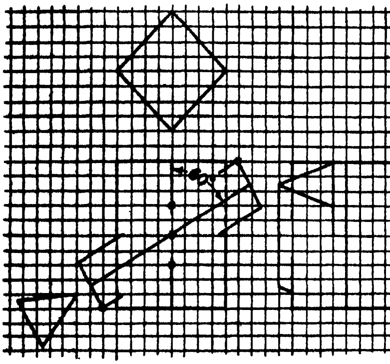


FIG. 128.

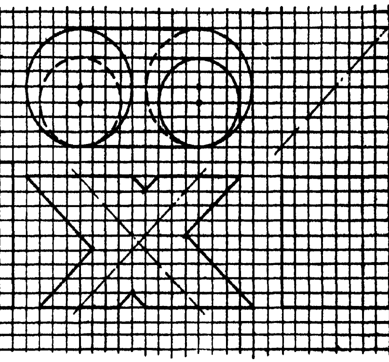


FIG. 129.

The bases are as 4 to 5 in diameter and the vertical height (not slant height) as 5. The distance between centers in the plan is also 5. If the smaller cylinder increases in diameter until equal to the larger, the intersection will become two 5″ circles, one in a horizontal plane, at mid-height of the cylinders, and one in a plane parallel to S. Show this by drawing the cylinders with radii 2″, and vertical height 5″. Solve by planes parallel to V. This solution will be preferable to the solution by planes parallel to H. It is interesting to note that the shape of the intersection in Fig. 125 is approaching this pair of circles.

135. In Fig. 130 test your understanding of orthographic projection by completing the drawings. No. 1 and No. 2 require a side view, and No. 3 requires both a right and a left side view.

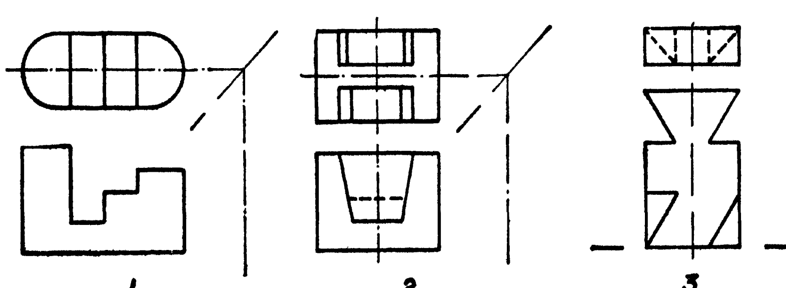


FIG. 130.

CHAPTER XIV

SET OF DESCRIPTIVE DRAWINGS

SHEET 5.

Octagonal Prism and Inclined Plane.

Lay out the sheet as described in Art. 139 of page 109. After the sheet is in the condition shown by Fig. 132, page 110, unpin it from the board, turn it 90° to the left, "counterclockwise," and tack it to the board square with the blade of the T-square. The V.C.L. becomes the H.C.L. and vice versa.

Plot an origin 1″ to the right of *C* and $4\frac{3}{4}''$ above *C*.

(a) Draw an octagonal prism, its axis being **P** ($1\frac{1}{2}''$, $1\frac{1}{2}''$, $\frac{1}{4}''$), **P′** ($1\frac{1}{2}''$, $1\frac{1}{2}''$, $5\frac{1}{8}''$). The base is an octagon in a plane parallel to $\mathbb{H}$, circumscribed about a circle of $1\frac{1}{4}''$ radius. The prism is intersected by a plane perpendicular to $\mathbb{V}$, its trace on $\mathbb{V}$ making an angle of 30° with **OZ** at the point **k** (0″, 0″, $5\frac{1}{4}''$) and inclining up to the left. Draw the $\mathbb{H}$, $\mathbb{V}$, and $\mathbb{S}$ projections of the prism, with the line of intersection of the plane marked on it, lettering the corners of the top base **A, B, C,** etc., beginning with **A** ($2\frac{3}{4}''$, 1″, $\frac{1}{4}''$) and **B** (2″, $\frac{1}{4}''$, $\frac{1}{4}''$). Letter the corresponding corners of the lower base **A′, B′, C′,** etc. Letter the point where **AA′** pierces the plane, **a,** etc.

(b) Make a drawing of the *true shape* of the intersection, **abc . . . h,** by projecting it on a plane perpendicular to $\mathbb{V}$ parallel to the cutting plane and having its trace on $\mathbb{V}$ through the point **l** ($3\frac{1}{2}''$, 0″, 4″). Letter all points without subscripts.

(c) Draw the *development* of the surface of the prism (neglecting the bases), with the line of intersection drawn on it, splitting the surface on the edge **AA′** and placing **A,** of the development, $6\frac{3}{4}''$ to the left of **O,** and $7\frac{5}{8}''$ below it [that is, at the point **m** ($6\frac{3}{4}''$, 0″, $7\frac{5}{8}''$)] and **A′** vertically below **A.** Letter all points. The line of intersection is to be inked as a standard line.

(d) Ink, following strictly the alphabet of lines on page 36, and following directions on pages 121 to 123. Colored lead pencils are part of the equipment and often a color is assigned to mark a special part or process. A colored line is not inked, of course.

Construction work should never be inked in a wholesale manner. On this sheet pick out for inking only that work necessary to locate one point of the true shape.

Inking of many drawing sheets is omitted for lack of time. In such a case look over the pencil work well, erase loose ends of lines, emphasize those too faint and erase smudges.

(e) The legend in freehand lettering is as follows:

1.		SHEET 5.	**(Freehand caps, $\frac{3}{8}''$ high.)**
2.		PRISM AND PLANE	**(Freehand caps, No. 8, L. T.)**
3.	Signature	4th Class, U.S.N.A.	**(No. 4, L. T.)**
4.		Date here.	**(No. 4, L. T.)**

The bottoms of the lines are $\frac{3}{8}''$ apart. The signature is already in place if the layout has been completed. The fourth line of the legend is $\frac{1}{2}''$ above the bottom border line. Pencil the legend and improve the spacing before inking it.

Notice that whenever a sheet is put on the board with the long dimension vertical, the legend stays in the position it would have on a horizontal drawing. A drawing, when filed away in a drawer, must have its legend in the lower right corner so that a desired drawing can be found by flipping up all the sheets and examining the legends one by one until the right one is found. The whole pile of drawings need not be removed from the drawer.

SHEET 6.

Pentagonal Pyramid and Inclined Planes.

Layout as on page 110, with $\mathbf{2\frac{1}{4}'' \times 5''}$ legend space. Take as origin a point 4″ to the left of *C*, and $1\frac{1}{2}''$ above *C*.

(a) Draw a pentagonal pyramid having its vertex at **P** ($1\frac{7}{8}''$, $1\frac{7}{8}''$, $\frac{1}{8}''$) and the center of the pentagonal base at **P′** ($1\frac{7}{8}''$, $1\frac{7}{8}''$, $3\frac{3}{8}''$). The pentagon is inscribed in a circle of $1\frac{3}{4}''$ radius in a plane parallel to $\mathbb{H}$, one corner, **A**, being at ($1\frac{7}{8}''$, $\frac{1}{8}''$, $3\frac{3}{8}''$). For describing the pentagon use the method of page 162 or space with dividers, finding proper length of side by trial and error, as described on pages 88 and 89. Draw the $\mathbb{H}$, $\mathbb{V}$, and $\mathbb{S}$ projections and letter the corners in each view, taking **B** to the right of **A**, etc.

(b) Draw the intersection of this pyramid with a plane perpendicular to $\mathbb{S}$, having its trace on $\mathbb{S}$ through the points **f** (0″, $\frac{3}{8}''$, $1\frac{5}{8}''$) and **g** (0″, $3\frac{5}{8}''$, $3\frac{3}{8}''$). In addition to the projections on $\mathbb{H}$ and $\mathbb{V}$, find the true shape of the intersection by projecting on a plane $\mathbb{U}$, perpendicular to $\mathbb{S}$ through the point **h** (0″, 0″, $3\frac{1}{2}''$). Letter the point where **PA** pierces the plane, **a**, etc. Use red pencil for this section, if available.

(c) Draw the intersection of the pyramid with a plane perpendicular to $\mathbb{S}$, having its trace on $\mathbb{S}$ through the point **j** (0″, $2\frac{9}{16}''$, 0″) and parallel to the edge **PA**. Find the true shape of this intersection on a plane $\mathbb{W}$, perpendicular to $\mathbb{S}$, through the point **k** (0″, $5\frac{1}{16}''$, 0″). Letter this polygon **mb′c′d′e′n.** There is no intersection with **PA,** therefore no **a′**, but a line of intersection with the base, **mn.** Use blue lead pencil for this paragraph.

(d) Draw the development of the surface of the pyramid, cutting along **PA**, etc., and put **P** 7″ to the right of the origin and $3\frac{1}{2}''$ above it. Put **A** to the right of **P** horizontally, and step backwards, clockwise, to **E**, **D**, **C**, **B**, and finally **A** again, much as on page 248. Attach the base **ABCDE** to the side **DE.** Draw the line **abcdea** in red and the line **mb′c′d′e′n** in blue. Show **mn** on the base, in blue.

(e) Ink as described on pages 121 to 124. Ink no red or blue lines. Ink a minimum of construction work.

(f) The legend is similar to that on the opposite page, with 6 for 5, but with the "title line" PYRAMID AND PLANES.

SHEET 7.

Octagonal and Triangular Prisms.

The layout is the standard one described by Fig. 132 of page 110. Draw the thumbtacks, turn the sheet 90°, counterclockwise, and retack it to the board, square with the T-square. Take as origin a point 2″ to the right of *C* on what is now the H.C.L.

(a) Describe an octagonal prism, the axis extending from **P** ($2\frac{1}{4}''$, $1\frac{3}{8}''$, $\frac{1}{4}''$) to **P′** ($2\frac{1}{4}''$, $1\frac{3}{8}''$, $4\frac{1}{4}''$). The bases are regular octagons in planes perpendicular to the axis, **PP′**, at its extremities. Each octagon is circumscribed about a circle of $2\frac{1}{4}''$ diameter, one flat side being parallel to the axis of **X**. Complete three views of the prism and letter the corners of the top base **A**, **B**, **C**, etc., and those of the bottom base **A′**, **B′**, **C′**, etc. **A** is the point ($2\frac{23}{32}''$, $\frac{1}{4}''$, $\frac{1}{4}''$) and **B** ($1\frac{25}{32}''$, $\frac{1}{4}''$, $\frac{1}{4}''$).

(b) Describe a triangular prism, whose axis, **Q** (0″.52, $1\frac{3}{8}''$, $1\frac{1}{4}''$) **Q′** (3″.98, $1\frac{3}{8}''$, $3\frac{1}{4}''$), intersects **PP′** at its middle point, making an angle of 60° with it. The bases are equilateral triangles **JKL**, and **J′K′L′**, circumscribed about 1″ circles, and their planes are perpendicular to **QQ′** at its extremities. One corner of the bottom base is **J′** (4″.46, $1\frac{3}{8}''$, 2″.38). Plot this point.

Draw four projections of this prism, in the order, $\mathbb{U}$, $\mathbb{V}$, $\mathbb{H}$, $\mathbb{S}$, as if the other prism were not present. The auxiliary plane of projection $\mathbb{U}$ is perpendicular to **QQ′** and its trace on $\mathbb{V}$ passes through the point **m** (6″, 0″, 0″). To draw the projection on $\mathbb{U}$, describe a circle with $\mathbf{Q}_u'$ as center and locate $\mathbf{J}_u'$. An equilateral triangle may be easily completed by drawing vertical and 30° lines tangent to the circle.

(c) Draw the projection of the octagonal prism on $\mathbb{U}$, remembering that the triangular prism *pierces* it, and that therefore no part of its edges exist in the space occupied by the triangular prism.

(d) Determine the line of intersection between the prisms by the method of Chapter IV. First locate **h** and **h′**, points where **HH′**

intersects the triangular prism. Immediately erase the portion of the line, **hh′**, since it cannot exist within the triangular prism. Next locate **c** and **c′** and **j** and **j′**, etc.

(e) Draw the development of the sides of the octagonal prism, with holes cut out to allow **QQ′** to pass through. Cut the surface on the line **AA′** and unroll it. Place the development in the upper right corner of the sheet.

(f) Ink and finish as usual. Erase nearly all the construction lines.

(g) The legend follows the standard form of Art. 137 of Part I or as given on p. 362. The title line reads INTERSECTING PRISMS.

SHEET 8.

Hexagonal Pyramid and Square Prism.

(a) Describe an hexagonal pyramid with vertex at **P** ($1\frac{3}{4}''$, $2''$, $\frac{1}{2}''$) and center of base at **P′** ($1\frac{3}{4}''$, $2''$, $3''$). The base is in a plane parallel to H and is a hexagon circumscribed about a circle whose diameter is $2\frac{1}{2}''$. One corner is the point **A** ($1\frac{3}{4}''$, $0''.56$, $3''$). **Draw** three views of this pyramid and letter its points in all. The next point to the right of **A** is **B.** Place origin $1''$ to left of center of sheet.

(b) Describe a square prism whose axis is **Q** ($\frac{1}{4}''$, $2''$, $2\frac{1}{4}''$) **Q′** ($3\frac{1}{4}''$, $2''$, $2\frac{1}{4}''$). The bases are planes parallel to **S** and the squares measure $1''$ on each edge. Draw the view on S first, the edges of the square there described being parallel to the axes of **Y** and **Z.** Letter the corners of the base nearest to S, **GHIJ**, **G** and **H** being the upper left and right corners of the S view. Letter the other base **G′H′I′J′**. Complete the three views of the prism as if the pyramid were not present.

(c) Draw an auxiliary projection of both figures on a plane U, perpendicular to H, whose trace on H makes an angle of 120° with the axis of **X** at the point **k** ($2\frac{5}{8}''$, $0''$, $0''$).

(d) Finish the drawing to represent one piece, not two. The object is cut from a solid and therefore the prism does not pierce the pyramid, nor does the pyramid pierce the prism. Erase surplus lines. Draw necessary broken lines for concealed edges.

(d) Draw the development of the slanting surface of the pyramid. Cut the surface along the line **PA.** Place **A** $3\frac{1}{2}''$ above the origin and $\frac{1}{4}''$ to the right of it, and **P,** $3\frac{1}{2}''$ above, and $3''.14$ to the right of the origin. Mark the line of intersection with the prism on this developed surface, as a standard line. Distances required for locating it must be taken from the regular views wherever they appear of their true length.

(e) Draw the development of the square prism to the right of the last figure above the legend space. Split the surface on **GG′.** Place one edge, **GG′**, of the development, $\frac{1}{4}''$ above the legend space,

and the other edge, **GG′**, $4\frac{1}{4}''$ above it. Describe the line of intersection with the pyramid on this development. True distances may be transferred by dividers from the $\mathbb{H}$ and $\mathbb{S}$ projections. Middle sections of **GG′** and **HH′** are cut out or at least made to show as construction lines (dash-dot-dot), for edges which no longer actually exist.

(f) Ink and finish as on pages 121-123.

(g) Legend as on p. 362. The title line reads, INTERSECTING PRISM AND PYRAMID.

SHEET 9.

Right Circular Cone and Inclined Plane.

Use the standard layout, Fig. 132 of page 110 with $2\frac{1}{2}'' \times 5''$ legend space. Take as origin a point $2''$ to the left of C and $1''$ above C.

(a) Draw a right circular cone, vertex at **P** ($2\frac{1}{2}''$, $2\frac{1}{4}''$, $\frac{1}{4}''$), center of base at **P′** ($2\frac{1}{2}''$, $2\frac{1}{4}''$, $4\frac{1}{2}''$), diameter, $4''$.

(b) The cone is intersected by a plane perpendicular to $\mathbb{S}$, its trace on $\mathbb{S}$ passing through **k** ($0''$, **A**, $\frac{1}{4}''$) and **l** ($0''$, $3\frac{1}{2}''$, $4\frac{1}{2}''$). For the letter **A** in the coordinates of **K** use one of these four values as directed by your instructor, $\frac{1}{2}''$, $1''$, $1\frac{1}{2}''$ or $1\frac{7}{8}''$. Check off here by pencil check mark which one you are directed to use.

(c) Using red pencil draw the line of intersection on plan and front view.

(d) Show, using blue pencil, the true shape of the curve by projecting to an auxiliary plane, $\mathbb{U}$, perpendicular to $\mathbb{S}$, whose trace on $\mathbb{S}$ passes through the point **m** ($0''$, $2\frac{3}{4}''$, $0''$).

(e) Ink as described on pages 121-123.

(f) Use the standard legend. See page 362. The title line reads CONE AND PLANE.

SHEET 10.

Inclined Cylinder and Plane.

Layout as usual. Take as origin a point on V. C. L., 2″ above *C*.

(a) Draw three views of an inclined circular cylinder, cut by a plane. The axis is **P** (**B**, $1\frac{7}{8}$″, $\frac{1}{4}$″), **P′** (**C**, $1\frac{7}{8}$″, $4\frac{1}{4}$″). The base is a circle of diameter **D**, in a plane parallel to $\mathbb{H}$. For **B**, **C**, and **D** use one of four sets of values as directed by your instructor. Check here by a pencil check mark which column you are directed to use.

	(1)	(2)	(3)	(4)
B =	4 ″	$4\frac{1}{2}$″	5 ″	3 ″
C =	3 ″	$2\frac{1}{2}$″	2 ″	4 ″
D =	$3\frac{1}{4}$″	3 ″	$2\frac{3}{4}$″	$2\frac{3}{4}$″

(b) The given plane is perpendicular to $\mathbb{V}$. Its trace on $\mathbb{V}$ passes through **p**, the middle point of **PP**, and is inclined up to the left at an angle of 30° with **OX**.

(c) Plot the line of intersection on $\mathbb{H}$ and $\mathbb{S}$, without using any method of construction peculiar to the ellipse. Follow the method of intersections of the intersections. Plot one quadrant on $\mathbb{H}$ and one on $\mathbb{S}$.

(d) To pass a smooth curve through the plotted points, use the method of the draftsman's ellipse, Art. 130, Part I, or Fig. 41, p. 263, *if it applies* to the ellipses found. Otherwise follow with irregular curves. See Art. 132, page 103. Repeat other quadrants "mechanically."

(e) Using green pencil find the true shape of the curve of intersection by projecting on a $\mathbb{U}$-plane, perpendicular to $\mathbb{V}$, whose trace on $\mathbb{V}$ contains the point **k** (5″, 0″, 4″).

(f) Ink as usual. See pages 121-123.

(g) Use standard legend, p. 362. The title is INCLINED CYLINDER AND PLANE.

SHEET 11.

Layout as usual. Plot a first origin, 3″ to the left of *C*, and $1\frac{3}{4}$″ below *C*, and a second origin, 4″ to the right of *C*, and $1\frac{1}{2}$″ above *C*.

First Origin: Intersecting Right Cylinders.

(a) Draw three views of a vertical right cylinder, axis **P** ($2\frac{1}{2}$″, 2″, $\frac{1}{2}$″), **P′** ($2\frac{1}{2}$″, 2″, $3\frac{1}{2}$″), diameter 3″.

(b) Draw three views of a horizontal right cylinder, axis **Q** ($\frac{1}{2}$″, **E**, 2″), **Q′** ($4\frac{1}{2}$″, **E**, 2″), and diameter, **F**. For values of the letters **E** and **F** your instructor will assign one of the following columns for you to follow. Check off by pencil mark that column you are to use.

	(1)	(2)	(3)	(4)
E =	$1\frac{9}{16}$″	$1\frac{7}{16}$″	$1\frac{7}{16}$″	$1\frac{1}{4}$″
F =	2″	$1\frac{7}{8}$″	2″	$2\frac{3}{8}$″
G =	$1\frac{1}{8}$″	$\frac{13}{16}$″	$1\frac{1}{8}$″	$1\frac{1}{2}$″
H =	$1\frac{3}{4}$″	$1\frac{1}{2}$″	$1\frac{1}{2}$″	$1\frac{3}{4}$″

(c) Determine the line of intersection. Solution 2 with planes at $\frac{3}{4}$″, 1″, $1\frac{1}{4}$″, etc., from $\mathbb{V}$ is easy. So also are solutions 1 and 3. 4 and 6 are possible but not advisable. Since the axes do not intersect, such points as *a* and *c* of Fig. 56 are not on the line of intersection at all. A critical plane through **PP′** gives points where the lines of intersection are tangent to the side elements of cylinder **PP′**. Another critical plane through **QQ′** gives points of tangency on the top and bottom elements of cylinder **QQ′**.

(d) Finish to show **QQ′** piercing **PP′**.

Second Origin: Intersecting Cylinder and Sphere.

(e) Plot a vertical right cylinder, axis **R** (2″, **G**, $\frac{1}{8}$″), **R′** (2″, **G**, $3\frac{7}{8}$″), diameter **H**. For values of **G** and **H** use the same column as for **E** and **F** above.

(f) Plot a sphere of $3\frac{1}{2}$″ diameter, center at **C** (2″, 2″, 2″).

(g) Determine the line of intersection, preferably using the same solution as before.

(h) Finish to show the cylinder, **RR′**, piercing the sphere, **C**.

(i) Ink sheet 11 in the standard manner.

(j) Use the standard legend, p. 362. The title is CYLINDERS AND SPHERE.

SHEET 12.

Get from your instructor a sheet of cross-section paper, with field of $15'' \times 20''$, ruled in inches and eighths. Plot four origins; $\mathbf{O}_1$, $3''$ below the top of field, $6''$ from the left edge; $\mathbf{O}_2$, $3''$ below the top edge, $4''$ from the right edge; $\mathbf{O}_3$, $4''$ above the bottom edge, $6''$ from the left edge; $\mathbf{O}_4$, $4''$ above the bottom edge, $4''$ from the right edge.

At all four origins plot an inclined circular cylinder, axis $\mathbf{P}$ $(4'', 1\frac{7}{8}'', \frac{1}{2}'')$, $\mathbf{P}'$ $(1\frac{31}{32}'', 1\frac{7}{8}'', 4'')$, a line at $30°$ with the vertical. The bases are parallel to $\mathbb{H}$ and of $2\frac{3}{4}''$ diameter.

These cylinders are pierced by horizonal right cylinders whose bases are circles of $2\frac{1}{4}''$ diameter, at distances of $\frac{1}{4}''$ and $5\frac{3}{4}''$ from $\mathbb{S}$. Their axes are $2\frac{1}{4}''$ below $\mathbb{H}$ and parallel to the axis of $\mathbf{X}$. The y-coordinates of $\mathbf{Q}$ and $\mathbf{Q}'$ differ in each case. Thus, at $\mathbf{O}_1$, $\mathbf{Q}$ is $(\frac{1}{4}'', 1\frac{7}{8}'', 2\frac{1}{4}'')$, at $\mathbf{O}_2$ it is $(\frac{1}{4}'', 1\frac{3}{4}'', 2\frac{1}{4}'')$ at $\mathbf{O}_3$ it is $(\frac{1}{4}'', 1\frac{5}{8}'', 2\frac{1}{4}'')$ and at $\mathbf{O}_4$ it is $(\frac{1}{4}'', 1\frac{1}{2}'', 2\frac{1}{4}'')$.

Use solutions 1 or 2. Watch the critical points.

If time allows move side view at $\mathbf{O}_4$ to abreast of the plan as in Fig. 5, p. 212. Put a standard legend in the space vacated. The title reads SET OF INTERSECTING CYLINDERS.

SHEET 13.

Surfaces of Revolution.

Lay out as usual. See Fig. 132, page 110. Take a first origin $\frac{1}{2}''$ to the left of C and $2\frac{1}{2}''$ above C, and a second origin $7''$ to the right of C and $1\frac{1}{4}''$ above C.

First Origin: Forked End of Connecting Rod.

This drawing, based on Fig. 131, requires two views only, the plan as shown and the front view to be completed.

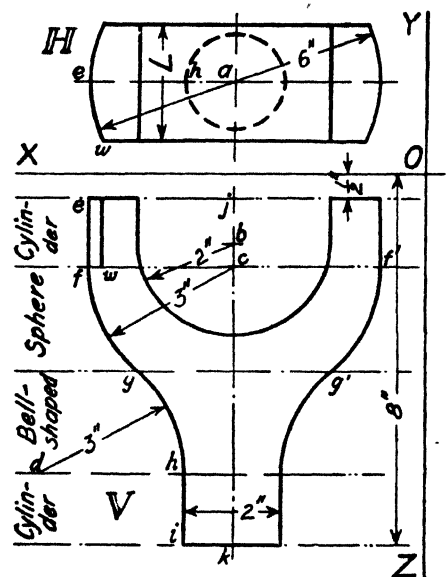


FIG. 131.

(a) The "Forked End" is commonly turned in a lathe and then faced off at the sides by a shaper. In this case it is faced to a width **L**. Any one of four values for **L** may be assigned: $2\frac{1}{8}''$, $2\frac{3}{8}''$, $2\frac{1}{4}''$, or $2\frac{1}{2}''$. Check off the one to be used in your case.

The center a ($4''$, $0''$, $2''$) is a point on the plane **H**. Plot it **on H only,** since it is to be used only for plotting the plan. Plot the points b ($4''$, $0''$, $1\frac{1}{2}''$) and c ($4''$, $0''$, $2''$) **on V only** and use them

only for the construction of the front view. Project the straight lines *ef* and *hi* from *e* and *h* of the plan. With *c* as center draw arcs *fg* and *g′f′*, with some excess in pencil. Draw the arc *gh* tangent to *fg* and *hi* (by the method of Art. 119, p. 91). The generating line *efghi*, taken as in a plane parallel to $\mathbb{V}$ at $1\frac{3}{4}''$ from $\mathbb{V}$, in its initial position, is revolved about the axis *jk*. Its parts, *ef, fg, gh* and *hi*, create respectively a short cylinder, part of a sphere, a bell-shaped surface and a second cylinder. These are in horizontal layers as marked at the left of Fig. 131.

(b) The facing to the width **L** creates a curve which starts at *w*, projected down from the corner seen on $\mathbb{H}$. Complete this line.

Second Origin: Ogival Point and Planes.

Views on $\mathbb{H}$ and $\mathbb{V}$ only are required. A shell point has the form of a cylinder with an "ogival point," like the point of Fig. 64 on p. 289. It is to be drawn and intersections with two planes determined.

(a) The axis of revolution is **P** ($3''$, $2\frac{1}{4}''$, $0''.19$), **P′** ($3''$, $2\frac{1}{4}''$, $4\frac{5}{8}''$). Plot the points **B** ($5''$, $2\frac{1}{4}''$, $3\frac{5}{8}''$), **C** ($1''$, $2\frac{1}{4}''$, $3\frac{5}{8}''$) and **D** ($1''$, $2\frac{1}{4}''$, $4\frac{5}{8}''$). On $\mathbb{V}$ draw an arc of a circle, center at $\mathbf{B}_v$, from $\mathbf{P}_v$ to $\mathbf{C}_v$, and extend it by a tangent at $\mathbf{C}_v$ to $\mathbf{D}_v$. Join $\mathbf{D}_v\mathbf{P}_v'$. $\mathbf{P}_v\mathbf{C}_v\mathbf{D}_v\mathbf{P}_v'$ is the front view of the generating line in its initial position. It generates the shell point by revolving about **PP′**. Draw the $\mathbb{H}$ and $\mathbb{V}$ views.

(b) A plane, **T**, parallel to $\mathbb{V}$ at a distance from $\mathbb{V}$ equal to the dimension **J** intersects the shell. For **J** (and **K**) you will be directed to use one of the four columns here:

	(1)	(2)	(3)	(4)
J =	$1\frac{1}{4}''$	$1\frac{3}{8}''$	$1\frac{5}{8}''$	$1\frac{1}{2}''$
K =	60°	45°	50°	55°

Draw in red the trace of **T** on $\mathbb{H}$, and on $\mathbb{V}$ its line of intersection.

(c) A plane, **R**, also cuts the shell. It is a plane perpendicular to $\mathbb{V}$, passing through the origin, and making an angle with the axis of **Z** given by the dimension **K** above. Draw in blue the trace of **R** on $\mathbb{V}$, and on $\mathbb{H}$ draw the intersection of **R** with the shell point.

(d) Finish the sheet and ink as usual.

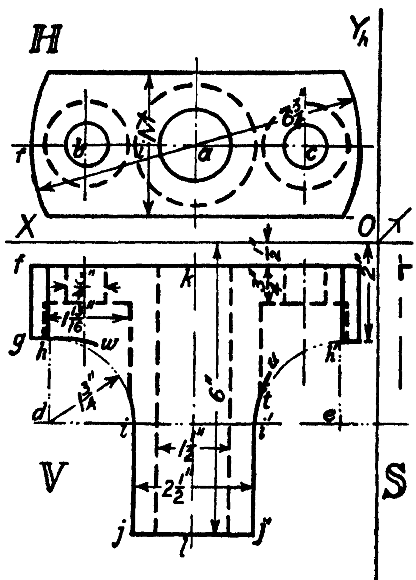
(e) In the legend title line reads SURFACES OF REVOLUTION.

SHEET 14.

Stub End of Connecting Rod.

Lay out the sheet as usual. Take as origin a point on the V. C. L., 2″ above *C*.

The Connecting Rods of many marine reciprocating engines have, at one end, a fork faced off like that of Sheet 13, and at the other a stub or flange for two bolts. Fig. 117 is the layout for a stub end faced off at the sides to the width **M** as given to you by your instructor. He will assign one of four values: $2\frac{5}{8}$″, 3″, $2\frac{7}{8}$″ or $2\frac{3}{4}$″. The stub end is bored for a pair of bolts with heads which are to fill the large counterbores below.



STUB END

FIG. 132.

(a) Plot first the centers *a* ($3\frac{3}{4}$″, 2″, 0″), *b* (6″, 2″, 0″), and *c* ($1\frac{1}{2}$″, 2″, 0″) **on** $\mathbb{H}$ **only.** Use them to construct the plan with the dimensions given in the figure.

(b) *d* (6¾″, 0″, 3¾″) and *e* (¾″, 0″, 3¾″) are centers to be used **on V only** for constructing the front view. Describe quadrants of circles *hi* and *i′h′*. Project *fg*, *i′j′*, etc., from the plan. Consider that the generating line *fghij*, situated in a plane, *fbac*, 2″ back of the plane of V, revolves about the center *a* as seen on H, or *kl* as seen on V. The various parts create surfaces of revolution as follows: *fg* a cylinder; *gh* a plane surface; *hi* a bell-shaped surface and *ij* a cylinder. The facing of the solid so formed to the width **M** creates curves of intersection. One is shown in the figure started at *h* and drawn as far as *w*. Complete this curve by using horizontal cutting planes, ⅛″ apart, from *h* down.

(c) The bell-shaped surface is cut into by the counterbores of 1 3/16″ diameter. Therefore large parts of the quadrants *hi* and *i′h′* are reduced from full lines to construction lines, and the edge of the metal which remains after boring is a line of intersection shown started as *tu*. It must be continued to *h′*. Read Art. 72, page 290. The same cutting planes as before are used and are extended further down.

(d) A side view to the right of V is required. Project from H and V. Two centers equivalent to *d* and *e* are needed. They are on the horizontal plane *de* and are at the same distance from the axis on S as *d* and *e* are from *kl*, the axis on V. One of these points belonging to the S view encroaches on the field of V. The arcs of 1¾″ radius are very short due to the facing off of the two sides.

(e) Project the point *t* to the center line on S. The line of intersection of the counterbore starting here is, roughly, a triangle with rounded corners, but only the top edge where the bore hole cuts the plane surface generated by *gh* is actually straight. Points of the curve at *u* were found by cutting planes and brought down to V from H. Project these points to S and draw the curve.

(f) Finish and ink as usual.

(g) The title line is STUB END OF CONNECTING ROD.

SHEET 15

Torus or Anchor Ring.

Lay out the sheet as usual. Take as origin a point on the H. C. L. 5″ to the right of C. At times, for this sheet, cross-section paper with a working field of 8″×13″ is issued. In that case take as origin the intersection of line 3, horizontal with line 11, vertical.

(a) An anchor ring **R**, is formed by revolving a circle of $1\frac{1}{4}''$ diameter, lying in a plane parallel to 𝕍 and with its center at **A** ($1\frac{1}{8}''$, $2\frac{3}{8}''$, $\frac{7}{8}''$), about an axis perpendicular to ℍ and piercing ℍ at the point **B** ($2\frac{3}{8}''$, $2\frac{3}{8}''$, $0''$). Draw plan, front elevation, right side elevation (to the right of ℍ), and left side elevation (to the left of ℍ) on plane 𝕊′, $4\frac{3}{4}''$ from 𝕊.

(b) A plane **P**, parallel to 𝕊 at $\frac{5}{8}''$ from 𝕊, cuts the ring. Draw the trace of **P** on ℍ, and the intersection of **P** and the ring on 𝕊. A second plane **P′**, parallel to 𝕊 at $1\frac{1}{8}''$ distance, cuts the ring. Draw the trace **P′H** and the intersection **P′R** on 𝕊. A third plane **Q** is parallel to 𝕍 at $1\frac{3}{4}''$ distance from 𝕍. Draw the trace **QH** and the intersection **QR** on 𝕍. A fourth plane, **Q′**, is parallel to 𝕍 at 2″ distance. Draw the trace **Q′H** and the intersection **Q′R** on 𝕍.

(c) An inclined plane **T** is perpendicular to 𝕊 and 𝕊′, its trace on 𝕊′ passing through the point **c** ($4\frac{3}{4}''$, $2\frac{3}{8}''$, $\frac{7}{8}''$), and inclining down to the right at such an angle as to be tangent to the projection on 𝕊′ of the generating circle when its center is at **d** ($2\frac{3}{8}''$, $1\frac{1}{8}''$, $\frac{7}{8}''$). Draw the trace of **T** on 𝕊′, and the intersection **TR** on ℍ.

(d) Find the true shape of **TR** by means of an auxiliary plane of projection 𝕌 perpendicular to 𝕊′, cutting 𝕊′ in a trace parallel to **TS′** through the point on 𝕊′ whose coordinates are **c**($4\frac{3}{4}''$, $0''$, $1\frac{1}{4}''$).

(e) Finish and ink as usual. The title line of the legend reads TORUS OR ANCHOR RING.

SHEET 16.

Cone and Double Ogival Point.

This problem can be solved only by Solution No. 7, that by auxiliary cutting spheres described in Art. 73.

Lay out the sheet as usual. Origin 2″ to right of *C*, $1\frac{1}{2}$″ above *C*.

(a) In this figure a cone pierces a double ogival point. It is a shape occurring in the inside cavity of a globe valve as will be seen in Part III, when the 3″ Navy Valve is illustrated. The cone has a vertical axis, **P** ($4\frac{1}{2}$″, $2\frac{1}{4}$″, $\frac{3}{8}$″), **P′** ($4\frac{1}{2}$″, $2\frac{1}{4}$″, 5″). **P′** is the center of the base, of $3\frac{3}{4}$″ diameter, in a horizontal plane.

(b) The double ogival point has as axis of revolution, **Q** ($\frac{9}{16}$″, $2\frac{1}{4}$″, 3″), **Q′** ($8\frac{7}{16}$″, $2\frac{1}{4}$″, 3″), a line $7\frac{7}{8}$″ long. The generating line is the arc of a circle of 6″ radius, of which **QQ′** is the chord. One position for the center of the arc is **k** ($4\frac{1}{2}$″, $2\frac{1}{4}$″, $7\frac{17}{32}$″). Plot **k** on $\mathbb{V}$, draw the initial position of the generating line, then finish three views of the fat cigar-shaped surface.

(c) Draw the lines of intersection, considering the cone to pierce the ogival shape. The main curve is a curved line on all three projections and is determined by using three or more cutting spheres, centered at **p**, the point of intersection of **PP′** and **QQ′**. Let the first sphere be of $3\frac{3}{8}$″ diameter, and draw the sphere itself on $\mathbb{V}$ only. It intersects the cone in a horizontal circle which is described on $\mathbb{H}$ as a circle and on $\mathbb{V}$ and $\mathbb{S}$ as straight lines. It intersects the cigar shape in two vertical circles which appear as a circle on $\mathbb{S}$ and as vertical straight lines on $\mathbb{V}$ and $\mathbb{H}$. Draw these intersections and from them locate four points of intersections of intersections on $\mathbb{H}$, two on $\mathbb{V}$, and two on $\mathbb{S}$. When these have been pricked in and labeled erase construction lines and describe a new sphere of $3\frac{5}{8}$″ diameter, and then one of $3\frac{1}{8}$″ diameter. The critical points are fairly obvious, on $\mathbb{V}$ and $\mathbb{S}$. Carry them from $\mathbb{V}$ or $\mathbb{S}$ and $\mathbb{H}$ and from $\mathbb{S}$ to $\mathbb{V}$ and $\mathbb{H}$. If more points are needed pass more spheres.

(d) A small curve of intersection at the top can be drawn from critical points alone. The four on $\mathbb{H}$ are almost on a circle. The three on $\mathbb{V}$ may be connected by a circular arc by method of Art. 121 of Part I, and the three on $\mathbb{S}$ similarly.

(e) Finish and ink as usual. The legend has as title line CONE AND DOUBLE OGIVAL POINT.

SHEET 17.

Screw Propeller.

Lay out as usual. See p. 110. Place origin $1\frac{1}{2}''$ to the right of C and $3''$ below C.

(a) In this problem two views only are required, a plan and a side view to the right of the plan. Draw axes of projection suited to this arrangement, **XOZ** horizontal, and **OY** vertical.

The problem is to draw the acting faces of three blades of a marine screw propeller. These are small parts of helicoidal surfaces.

(b) The hub is a cylinder, $4\frac{1}{2}''$ long, diameter $1\frac{3}{4}''$. The axis is the line **P** ($4\frac{1}{2}''$, $4\frac{1}{2}''$, $\frac{1}{2}''$) **P′** ($4\frac{1}{2}''$, $4\frac{1}{2}''$, $5''$). The propeller is a right-hand screw, having three threads, or helicoidal surfaces.

(c) The first blade may be described as follows: Plot the line **A** ($\frac{1}{2}''$, $4\frac{1}{2}''$, $\frac{1}{2}''$) **B** ($3\frac{5}{8}''$, $4\frac{1}{2}''$, $\frac{1}{2}''$). Let it revolve about **PP′** clockwise, and travel along it, describing a helicoid of $9''$ pitch. On the plan draw a circle of $8''$ diameter with center at **P**. Make it a construction line and divide it into arcs of $10°$. On $\mathfrak{S}$ plot points for the outside and inside helices for the half-pitch length, the length of the cylinder, and draw in the curves by the methods of page 297. An axial movement of $\frac{1}{4}''$ corresponds to a rotation of $10°$.

(d) The only portion of this surface which is used for the actual driving surface of the propeller blade is that which lies within the confines of a "non-circular" cylinder, whose non-circular directrix we will approximate to with circular arcs. On the plan plot the center **c** ($4\frac{1}{2}''$, $2''$, $0''$) and with radius of $1\frac{1}{2}''$ describe a semicircle of which **a** ($4\frac{1}{2}''$, $\frac{1}{2}''$, $0''$) is the middle point. Letter these points and letter the extremities of the semicircle **d** and **e**. The line **ac**, extended to the cylinder, to the point **b**, is the middle line of the blade. With **d** as center and **de** as radius, describe an arc **ef** tangent to the semicircle and terminating on the cylinder at **f**. In the same way with **e** as center and **ed** as radius, describe an arc **dg** terminating on the cylinder at **g**. If a generating line, parallel to **PP′**, moves so that its trace on $\mathfrak{H}$ follows the directrix **feadg**, a non-circular cylinder is described. This cylinder intersects the helicoid.

(e) Find this line of intersection and describe it as a full standard line, except where hidden by the cylinder.

(f) The plan views of the other two blades are exactly similar loops, but they are at angles of 120° from the blade **ab**. Describe these blades by a mechanical repetition and letter them **a′b′** and **a″b″**. A straightforward manner of describing the side view of **a′b′** would be to draw a new helicoidal surface described by a line **A′B′** and find the intersection of surfaces as before. A simpler way is to make a step-by-step comparison with the blade **ab**, realizing that it is only necessary to rotate **ab** through 120° to make it make the exact place of **a′b′**. Thus, project the points **a′** and **b′** horizontally from plan to side view, and on the side view project vertically up from **a** or **b**. Letter these points **a′** and **b′** on the side view. These are corresponding elements. For an element 10° away from **a′b′** project horizontally from the plan and vertically from the corresponding element of the blade **ab**. By working each way from the middle line the whole blade may be plotted without confusion. The blade **a″b″** will be exactly similar on the side view, but turned oppositely.

(g) In finishing the drawing, consider that the only real objects are the cylinder and the three blades, and that any portion of a blade which disappears behind the cylinder must be drawn with standard broken lines.

(h) Legend as on p. 362. The title line reads SCREW PROPELLER.

SHEET 18.

Long Pitch Worm Thread.

Lay out as usual. Origin 1″ to left of *C* and 2″ below *C*. If paper ruled in inches and eighths with a field of 8″×13″ is issued instead of a white sheet, put origin at intersection of horizontal line, 2, and vertical line, 5. Draw as axes of coordinates a horizontal line *XOZ* and a vertical line *OY*. We are to make a drawing of two views only, **H** and **S**, arranged as on Fig. 5, p. 212, with the space for **V** discarded. The problem is to draw two views of a long pitch worm thread like that of page 302, but with two of the three threads, there shown, stripped off.

(a) The core cylinder has as axis **P** ($2\frac{3}{4}''$, $2\frac{3}{4}''$, $\frac{1}{2}''$), **P′** ($2\frac{3}{4}''$, $2\frac{3}{4}''$, 8″). Diameter $2\frac{1}{4}''$.

(b) On **S** plot the points **a** ($2\frac{3}{4}''$, $3\frac{7}{8}''$, $\frac{1}{2}''$), **b** ($2\frac{3}{4}''$, $5\frac{1}{4}''$, 1″), **c** ($2\frac{3}{4}''$, $5\frac{1}{4}''$, $1\frac{1}{2}''$), and **d** ($2\frac{3}{4}''$, $3\frac{7}{8}''$, 2″). Connect **ab** and **cd** by construction line, dash-dot-dot. Connect **bc** by a full line. Erase line from **a** to **d**. This is the profile for one thread projecting from the core cylinder, the thread and the core being one piece of metal.

(c) The thread is a right-hand thread of 6″ pitch. It extends the full length of the core cylinder and is faced off at the ends by the same planes which contain the bases of the core cylinder. Describe large helices (5″ diameter) from **b** and **c**, and small ones ($2\frac{1}{4}''$ diameter) from **a** and **d**. All are $7\frac{1}{2}''$ long (one turn and a quarter). Use $\frac{1}{2}''$ spaces along the axis and increments of 30° on the circumferences. Where needed insert half spaces. Show concealed edges by broken lines. On **H** part of the base circle for the core cylinder becomes a broken line.

(d) Determine the intersection of the planes through *P* and *P′* with the helicoidal surfaces by the method of Fig. 70-E, p. 302. Note the initial position of **ab** on **H**. Rotate it backward through quarter spaces. Thus the point **b** on **S** moves axially $\frac{1}{8}''$ to the left along its helix. Mark these positions $\mathbf{b}_{-7\frac{1}{2}}$, $\mathbf{b}_{-15}$ and $\mathbf{b}_{-22\frac{1}{2}}$. Mark them also on **H** for the backward motion of $7\frac{1}{2}°$, 15° and $22\frac{1}{2}°$. Do the same for **a**. On **S** this will require the continuation of the small helix beyond its core cylinder to the left. On

both views join $\mathbf{a}_{-7\frac{1}{2}}\,\mathbf{b}_{-7\frac{1}{2}}$, $\mathbf{a}_{-15}\,\mathbf{b}_{-15}$ and $\mathbf{a}_{-22\frac{1}{2}}\,\mathbf{b}_{-22\frac{1}{2}}$. Find where each line pierces the plane through **P** on the $\mathbb{S}$ view and project such point to the $\mathbb{H}$ view. The curve of intersection on $\mathbb{H}$ will be defined by five points. Fit a smooth curve to it and use it for the necessary repeats and reversals.

(e) Trace the point **a** to its position $\mathbf{a}_{120}$ and the point **b** to $\mathbf{b}_{120}$, on the $\mathbb{S}$ view. Join $\mathbf{a}_{120}\,\mathbf{b}_{120}$. This line is seen to bridge a gap from one helix to the other. Find a very flat smooth curve to fit as a tangent to this line and to the two helices. Mark the part used and use it at three similar places such as $\mathbf{c}_{60}\,\mathbf{d}_{60}$.

(f) If time permits two more similar threads may be wound around the core. However, omit all concealed edges at the back. This is for fast men only.

(g) Ink and finish as usual. The legend has as title line LONG PITCH WORM THREAD.

SHEET 19.

Cylinder and Cone, Developed.

Lay out as on p. 110. Origin on H.C.L., $3\frac{1}{2}''$ to left of *C*.

(a) Plot a cone, axis **P** ($2\frac{1}{8}''$, $2\frac{1}{8}''$, $\frac{1}{4}''$) **P′** ($2\frac{1}{8}''$, $2\frac{1}{8}''$, $2\frac{3}{4}''$). The base centered at *P′* is a circle of $3\frac{3}{4}''$ diameter.

(b) Plot a cylinder, axis **Q** ($\frac{1}{4}''$, **N**, $1\frac{5}{8}''$) **Q′** ($4''$, **N**, $1\frac{5}{8}''$), diameter $1\frac{7}{8}''$. For value of **N** use one of four values, $1\frac{13}{16}''$, $1\frac{9}{16}''$, $1\frac{1}{4}''$ or $1\frac{1}{16}''$, as assigned. This cylinder pierces the cone. The problem is like Fig. 59-A, page 283-B, except that **QQ′** is nearer to $\mathbb{V}$ than **PP′**.

(c) Solve the intersection by Solution No. 1 or No. 4. For Solution No. 1 divide the rim of cylinder on $\mathbb{S}$ into 24 equal parts and locate the horizontal cutting planes through the points of division. For Solution No. 4 divide the base of the cone on $\mathbb{H}$ into 24 parts by radiating lines. They represent cutting planes, containing **PP′**, at angles of 15° with each other, like Fig. 58, Art. 68.

(d) Add all the lines necessary for the solution not used above. They will be needed for the developments.

(e) Develop the surface of the cylinder, like Fig. 75, p. 306, turned 90°. The development will be $3\frac{3}{4}''$ wide and $\pi \times 1\frac{7}{8}'' = 5''.89$ high. Place it just above the legend space. Subdivide into 24 panels numbering the lines from 0 to 24. Now number the 24 points on the end of the cylinder on $\mathbb{S}$, clockwise, from 0 to 23, beginning at top, or, if any element is entirely clear of the cone, begin with it. Lay off on corresponding lines of the development the appropriate true lengths taken from the $\mathbb{V}$ or $\mathbb{H}$ views.

(f) Develop the surface of the cone as on page 308. Place **P** on the V.C.L., $4''$ above C, and 0, $3\frac{1}{8}''$ to the left of **P**. $3\frac{1}{8}''$ is the slant height of the cone. The radius of the base is three-fifths of $3\frac{1}{8}''$, or $1\frac{7}{8}''$. The sector is therefore $\frac{3}{5} \times 360° = 216°$. Subdivide it into 24 parts and number points from 0 up to 12 and down again to 0. On the $\mathbb{H}$ view number the points on the base of the cone from 0 at the top, both right and left, to 12 at the bottom. On each line of the development the true length of the corresponding line on $\mathbb{H}$ must be laid off. This is explained on p. 309, third paragraph.

(g) Ink as usual. Legend standard, reading CYLINDER AND CONE DEVELOPED.

SHEET 20.

Make the sheet identical with Sheet 19 except that N has the value $2\frac{1}{8}''$. Axes intersect as on Fig. 59-A, page 283-B.

SHEET 21.

Traces of Lines and Planes.

Lay out the sheet as usual. See p. 110. Plot five origins as follows. First origin, 5″ to left of *C* and $3\frac{1}{2}$″ above *C*; Second origin, $\frac{1}{2}$″ to right, $5\frac{1}{2}$″ up; Third origin, 6″ to right and 3″ up; Fourth origin, $4\frac{1}{2}$″ to left and $1\frac{3}{4}$″ down; Fifth origin, 3″ to right and $\frac{1}{2}$″ down.

First Origin.—A line has positive traces **A** ($1\frac{7}{8}$″, 0″, $1\frac{1}{8}$″) and **B** ($\frac{3}{4}$″, $1\frac{1}{2}$″, 0″). Find **C,** its negative trace.

Second Origin.—A line has positive traces **A** ($1\frac{1}{2}$″, 0″, $\frac{3}{4}$″) and **C** (0″, 3″, $2\frac{1}{4}$″). Find **B,** the negative trace. Plane H is not needed.

Third Origin.—**PH** passes through **E** (2″, 2″, 0″) and **b** (0″, $\frac{1}{2}$″, 0″) and **PS** passes through **F** (0″, $1\frac{1}{2}$″, 2″) and **b.** Find **PV,** the negative trace of **P.**

Fourth Origin.—Plot the line **E** (2″, $\frac{1}{2}$″, $\frac{3}{4}$″) **F** ($\frac{3}{4}$″, $1\frac{3}{4}$″, $\frac{1}{4}$″). Find the trace of the plane containing **EF** and the point **a** ($3\frac{1}{4}$″, 0″, 0″).

Fifth Origin.—Plot three points, **A** ($2\frac{1}{2}$″, $\frac{1}{4}$″, $\frac{1}{2}$″), **B** (2″, $\frac{1}{8}$″, 1″), and **C** ($\frac{7}{8}$″, $1\frac{1}{4}$″, $\frac{1}{4}$″). Find traces of the plane containing them.

Finish and ink as usual, see p. 362. The title line of the legend reads TRACES OF LINES AND PLANES.

SHEET 22

Intersections of Planes.

Lay out sheet as usual. Plot four origins as follows: Sixth origin, 3″ to left of *C*, and $3\frac{1}{2}$″ above *C*: Seventh origin, $7\frac{1}{2}$″ to right and $2\frac{1}{2}$″ up: Eighth origin, 4″ to left and $3\frac{1}{2}$″ down: Ninth origin, $2\frac{1}{2}$″ to right, 2″ down.

Sixth Origin.—The plane **P** has trace **PH** through **C** (2″, 2″, 0″) and **a** ($4\frac{1}{2}$″, 0″, 0″), and trace **PV** through **B** ($2\frac{1}{2}$″, 0″, 2″), and **a.** The plane **Q** has trace **QH** through **D** ($\frac{1}{2}$″, 2″, 0″) and **e** (3″, 0″, 0″), and trace **QV** through **B** and **e.** Find the projections of the line of intersection, **PQ.**

Seventh Origin.—The plane **P** has trace **PH** through **C** (5″, 2″, 0″) and **a** (6″, 0″, 0″), and trace **PV** through **D** ($3\frac{1}{2}$″, 0″, $1\frac{1}{4}$″) and **a.** The plane **Q** has trace **QH** through **E** ($3\frac{1}{2}$″, $2\frac{1}{4}$″, 0″) and **e** ($\frac{1}{2}$″, 0″, 0″), and trace **QV** through **F** ($1\frac{5}{8}$″, 0″, $1\frac{1}{2}$″) and **e.** Find the projections of **PQ.**

Eighth Origin.—**PH,** the trace on H of the plane **P,** is a line parallel to $\mathbf{OY_h}$, 3″ to the left. **PS** is a line parallel to $\mathbf{OY_s}$, 1″ below it. **QH** is a line parallel to $\mathbf{OY_h}$, 1″ to the left, and **QS** is a line parallel to $\mathbf{OY_s}$, 2″ below it. Find the projections of **PQ.**

Ninth Origin.—The plane **P** has trace **PH** through the points **G** ($3\frac{7}{8}''$, $2\frac{1}{4}''$, $0''$) and **a** ($\frac{1}{2}''$, $0''$, $0''$), and trace **PV** through **J** ($3''$, $0''$, $2\frac{1}{2}''$) and **a**. Find where the line **A** ($2\frac{1}{2}''$, $\frac{1}{8}''$, $\frac{1}{2}''$) **B** ($\frac{1}{2}''$, $1\frac{5}{8}''$, $1\frac{1}{2}''$) pierces it.

Finish and ink as usual. The title line reads INTERSECTIONS OF PLANES.

SHEET 23.

Cylinder and Oblique Plane.

Lay out sheet as usual. Take as origin a point $1\frac{1}{4}''$ to left of *C* and $1''$ below *C*.

This problem is similar to that of Fig. 110, page 339, with the exception that the cylinder is a right cylinder. Its diameter is $2\frac{1}{2}''$. The axis of the cylinder is **Q** ($2\frac{1}{4}''$, $1\frac{1}{2}''$, $\frac{1}{4}''$) **Q′** ($2\frac{1}{4}''$, $1\frac{1}{2}''$, $4''$) and the plane **P** has as intercepts on the axes, **a** ($6''$, $0''$, $0''$), **b** ($0''$, $7\frac{1}{2}''$, $0''$) and **c** ($0''$, $0''$, $5''$). The point **d** is ($0''$, $1\frac{1}{2}''$, $0''$). Draw $\mathbf{d_h h}$, perpendicular to **ab** and $\mathbf{d_s s}$ parallel to **Oc**. These are the traces of the plane $\mathbb{U}$. Develop $\mathbb{U}$, draw on it the cylinder **QQ′** and **PU**, the trace of the plane **P**. Continue solution by means of cutting planes **T**, parallel to $\mathbb{H}$.

Finish and ink as usual. The title line reads CYLINDER AND OBLIQUE PLANE.

SHEET 24.

Intersecting Cones.

Lay out the sheet as usual. Untack the sheet, turn it 90° counter-clockwise and retack in vertical position, square with blade of T-square. Take as origin a point $1\frac{1}{2}''$ to right of *C* and $3''$ above *C*.

The problem is one which can be solved only by *Solution No.* 8 mentioned in article 74, that which uses auxiliary cutting planes perpendicular to the $\mathbb{U}$ plane. It is a problem similar to Fig. 113 of p. 343 with the change of the cylinder in that figure to a second cone.

Draw two intersecting inclined cones. The first cone has its vertex at **P** ($1''$, $1\frac{7}{8}''$, $\frac{1}{4}''$), and the center of its base at **P′** ($2\frac{11}{16}''$, $1\frac{7}{8}''$, $4\frac{3}{4}''$). The base is a circle of $3\frac{3}{8}''$ diameter, lying in a plane parallel to $\mathbb{H}$. The second cone has its vertex at **Q** ($5''$, $1\frac{7}{8}''$, $2''.56$), and the center of its base at **Q′** ($\frac{1}{2}''$, $1\frac{7}{8}''$, $3\frac{1}{4}''$). The base is a circle of $3''$ diameter lying in a plane parallel to $\mathbb{S}$. Draw plan, front elevation, side elevation, and an auxiliary projection on a plane $\mathbb{U}$, perpendicular to the line **PQ**, the trace of $\mathbb{U}$ on $\mathbb{V}$, passing through the point $\mathbb{M}$ ($7\frac{1}{4}''$, $0''$, $0''$). Determine the line of intersection of the cones by auxiliary cutting planes containing the line **PQ**, and treat the problem on the supposition that the cone **PP′** pierces the cone **QQ′**.

Finish and ink as usual. The title line reads INTERSECTING CONES.

PART III

ENGINEERING DRAWING

A TREATISE ON ORTHOGRAPHIC PROJECTION
AS APPLIED TO ENGINEERING DRAWING, WITH THE RECOGNIZED
CONVENTIONAL ABBREVIATIONS USED IN PRACTICE

BY

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NEW YORK

JOHN WILEY & SONS, Inc.

LONDON: CHAPMAN & HALL, LIMITED

1941

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PREFACE

This part is intended to be a complete textbook on Engineering or Mechanical Drawing, suited to the needs of engineering students who have a satisfactory knowledge of the handling of instruments (treated in Part I) and of the principles of Descriptive Geometry (treated in Part II).

The aim set for this work by the Head of the Department of Engineering at the U. S. Naval Academy was at one time expressed as follows:

To develop in every midshipman:

(a) Ability to make working sketches.

(b) Ability to render simple mechanical and machine drawings.

(c) Ability to read blueprints—even complicated assemblies of a highly technical kind.

(d) Some understanding of machinery and of the function of parts in operation.

This work was first used at the Naval Academy in 1917 and has been revised many times since.

The revision of 1941 has greatly increased and systematized the chapter on describing and dimensioning, explaining the views, sections, methods of dimensioning, the application of labels, and the manufacturing methods they direct.

The chapter on elements of machine design is intended to familiarize the student with a number of common parts of machines and their names and functions.

Three chapters treat of sketching in orthographic and isometric forms, and two chapters explain the common forms of bolts, nuts, rivets, and screws and the methods of representing them.

The chapter on pipe fittings gives a survey of present naval practice for various pressures up to 600 lb. psi.

Short chapters explain the general principles and purposes of detail and assembly drawings.

A final chapter, "Set of Engineering Drawings," provides a framework for selecting drawing sheets to illustrate the subjects covered by the previous chapters. Only a few are in a form ready for assignment. Those who administer the drawing course have a large stock of subjects, especially of detail drawings, ready for assembly, or of assembly drawings for making sheets of details. Assignment of such subjects and of newly received material keeps the course from becoming rigid and inflexible.

A set of Tables of Standards, printed on yellow paper, and a general index complete the book.

The tables cover, in the first four pages, the standardized lines, views, sections, hatching, and conventional methods of representing screw threads. A set of five pages then tabulates the dimensions of the most used bolts, screws, nuts, and rivets. Eight more pages give the standard sizes of pipes and the simpler fittings and flanges, from the malleable and cast iron fittings for low pressures to the steel pipes, fittings, and spherical-back steel flanges for pressures to 600 lb.

T. W. J.

June, 1941

CONTENTS

PART III

CHAPTER I

DESCRIBING AND DIMENSIONING

1. What Describing Aims At.—In Part II, Descriptive Geometry, we discussed planes, cylinders, cones, spheres, etc. We defined our solids by giving the coordinates of the corners, centers of bases, etc.

In the practical application to engineering or mechanical drawing we meet the same surfaces but often in very fragmentary form. Small parts, as well as large parts, of well-known surfaces are quite commonly used.

To describe any piece of a machine, so that its form may be grasped in the most vivid manner, and in a minimum of time, is the special province of the detail drawing, or shop drawing, of small machine parts.

Let us look at the problem from the point of view of a mechanic who is required to manufacture each piece, so accurately that it may serve as intended. Every drawing must be the description of its piece so exact and so precise that our supposed mechanic should be able to make it from the drawing alone.

2. Combination of Methods in Describing.—Many a piece is of such complicated form that to describe it in words would require pages, and the chances of confusion would be great. We make a *drawing,* instead, hoping to present to the eye at a glance the main features of the piece, in "graphic" manner.

But the drawing itself may become too complicated if strict adherence to every theoretical line is attempted. We resort then to bits of *written description.* It may be but a word, as "drill" or "grind," or a phrase as "tap for $\frac{1}{2}''$ NPT" (National Pipe Thread).

A drawing is supposedly to an exact scale and fairly accurate. However, lines closer together than a thirty-second of an inch are easily confused. The typical drawing is therefore fortified by ***dimensions*** which give all the important distances needed for manu-

facture. This saves much measurement of the drawing by the mechanic and many chances of error. Dimensions are relied on entirely for minute differences in size, and in cases of discrepancy **the dimension has greater authority than the scale applied to the drawing.**

The typical drawing of a piece of machinery is therefore an abbreviated orthographic projection, helped out by phrases directing the process of manufacture, and overlaid with dimensions to give the exact sizes, so that chance of error is minimized.

3. Where Accuracy Is Needed.—Pieces have usually some "working faces" or "faying surfaces" where they are in contact with other pieces. At such places accuracy is essential. Other faces merely limit the amount of material which supports or backs up the working faces. At such places considerable variation is not serious. For example, in making a casting a pattern is given "draft" by altering unimportant surfaces so that it may draw out easily from the sand. One must be on guard, and use common sense, as to the degree of accuracy required for different parts of an object. Too much accuracy where accuracy is not needed means unnecessary cost of manufacture. Lack of accuracy where accuracy is needed means the loss of a piece or loss of time in correcting it.

Engineering today requires maximum results from minimum expenditure.

4. Views of the Drawing.—The drawing which consists of $\mathbb{H}$, $\mathbb{V}$ and $\mathbb{S}$ projections without axes, is the commonest. However, the side view is as often to the right of the plan as to the right of the front view. Also the *left side view* is not uncommon, and may be abreast the plan or the front view. Thus in practice the side view has four possible positions. Choice between them may depend on the shape of the paper to be drawn on, or on the compactness of the resulting whole. Choice between right and left side views often inclines towards that side which gives the minimum number of broken lines for concealed edges. For example, in Fig. 3, p. 211, the view $\mathbb{S}$ is preferable to $\mathbb{S}'$.

One of the regular views may be a *partial view,* like the plan in Fig. 120, p. 354. This is all of that view that is really valuable in the shop. A regular view may be divided into two partial views in

order to avoid broken lines which in quantity confuse a drawing. In Fig. 1 two half side views reduce the use of broken lines.

An auxiliary view at an angle, the familiar projection on a $\mathbb{U}$ plane, is much used. See the figures on page 354. The auxiliary view is often a partial view also.

5. Names of Views.—The three views are often called "plan," "front view" and "side view," but not necessarily so. One must not expect the strict terminology of descriptive geometry in practical drawing.

Many pieces require two views only. Such a pair of views may be called "front view" and "side view," if the relationship is that of $\mathbb{V}$ to $\mathbb{S}$. But they may also be called "side view" and "end view," or "longitudinal view" and "transverse view."

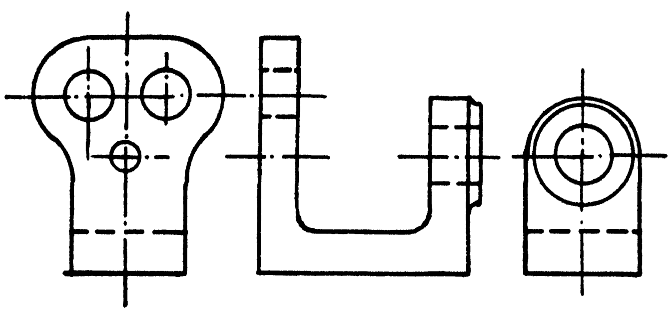


FIG. 1.

Some objects by their nature give names to certain views. Any vehicle of transportation, be it locomotive, motor car or airplane, will have its "front," "side" and "rear" views named from its direction of motion, not from the usual planes of projection.

One must use common sense in dealing with views and names of views in practical drawing, but still, in a good drawing, the laws of projection are followed rigidly, but without axes.

6. Use of Half Views.—A half view is a view in which half is cut away *to save space.* It differs from a section in which half is cut away *to expose the interior.* The saving in space often enables the drawing to be made to a larger scale, which adds to the clearness of the drawing.

Half views are used only for symmetrical pieces in which the missing half is obviously the opposite of the half which is given.

The half nearest to an adjacent view is discarded, and the remaining half is moved in to make it compact.

Figs. 2 and 3 are drawings of the same piece, a pipe tee with undrilled flanges. Fig. 3 is to a larger scale yet it occupies less space than Fig. 2. In 2 we have a plan, a front view, and a partial side view. In 3 a half plan, a front view, and a partial half side view. The half views, having one side bounded by a *center line,* not a solid edge, look unfinished. This suggests the need of the other half to complete the view.

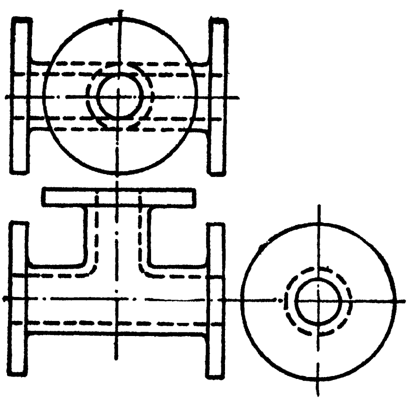


FIG. 2.

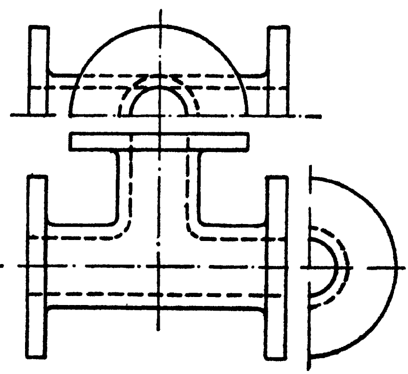


FIG. 3.

7. Sectional Views in General.—Sectional views or "sections" are used when the interior of an object is complicated and cannot be clearly shown by outside views. In a section the view is made as if a large part of the object were cut away and destroyed, but only so far as that particular view is concerned.

Fig. 4 is a typical example. It represents a cast iron base to which other pieces are to be welded or bolted. As shown the plan represents the complete piece.

The front view has been altered to become what is known as a "section-on-the-front-view" or a "front-view-in-section." The nearer half of the object has been removed, and we must imagine

that a saw has cut the piece on the H.C.L. of the plan, *mn,* and the imagined sawed surface is shown lined with equally spaced slanting lines, indicating, according to the Standard Hatching, page 545, that the piece is made of cast iron.

Section lining or "hatching" probably originated as showing the marks left on the piece by the teeth of the saw which cut it. It is very necessary to show that the cut is imaginary only, and not to be carried out actually when manufacturing the piece from the drawing. Hatching does this.

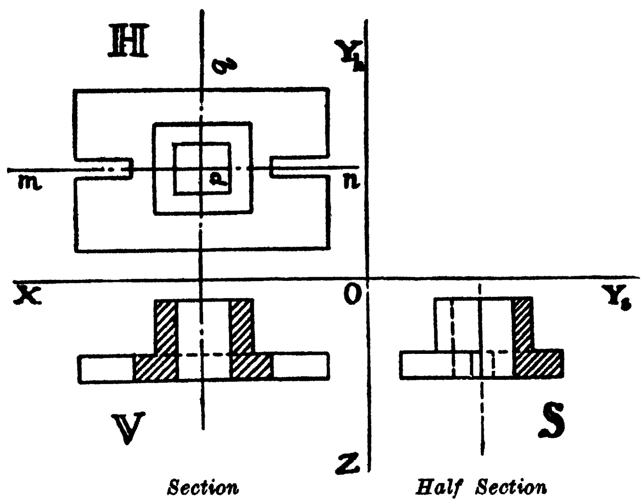


FIG. 4.

We note now that a section on a view means, in general, that *half* of the piece has been removed, theoretically.

There is an exception to be made. Not always is the exact half removed. When the plane of the saw cut would split in half an already thin section, and give, by the hatching, an air of solidity and mass which the piece may not really have, a part of the cutting plane may be boldly moved forward, enough to clear the thin section or "rib," leaving the area in question to be blank and not hatched in the sectional view.

This is seen in Fig. 5 where a pipe elbow of cast iron is shown by a "flange view," or end view, and a side-view-in-section.

This ell has a strengthening rib joining the two flanges. The plane of the section is the V.C.L. of the flange view, except that in the region in which the plane of symmetry represented by the V.C.L. would split the rib itself, the cutting plane takes a jog to the right. Thus in the section the area marked *A* is not hatched. If it were there would seem to be a heavy mass of cast iron at one spot.

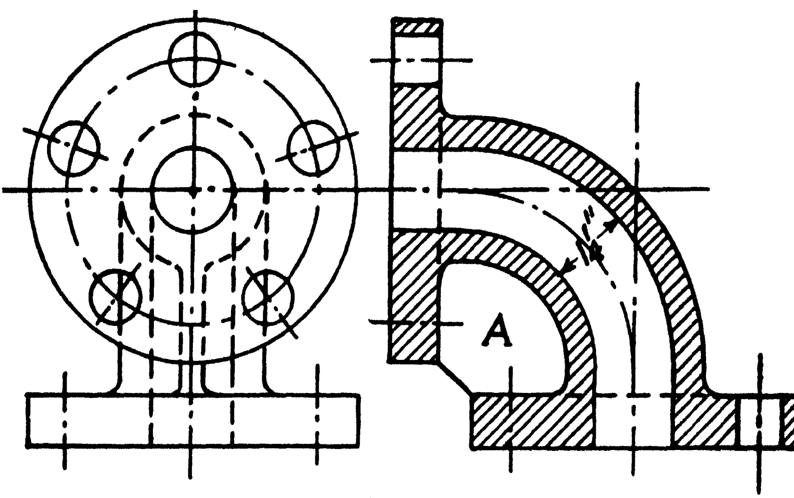


FIG. 5.

This offsetting of the cutting plane to avoid a thin rib is well known to all draftsmen and is used without mention of any kind. No path of section is marked.

8. The Half Section.—The side view of Fig. 4 is a "half section," not a "section" or "full section." It is in this case a "half-section-on-the-side-view" or a "side-view-half-in-section."

It represents the piece with *one quarter* cut away. The plan is imagined cut along the lines *pq* and *pn* and the NE corner removed.

9. The Partial Section, Part Section or "Broken-Out" Section.—In Fig. 6 at the lower left corner is shown a partial section. The

front view is constructed as if on the plan one had started to saw along the H.C.L. from the left and, after sawing a short distance, had pried out or broken out a part of the object on the near side.

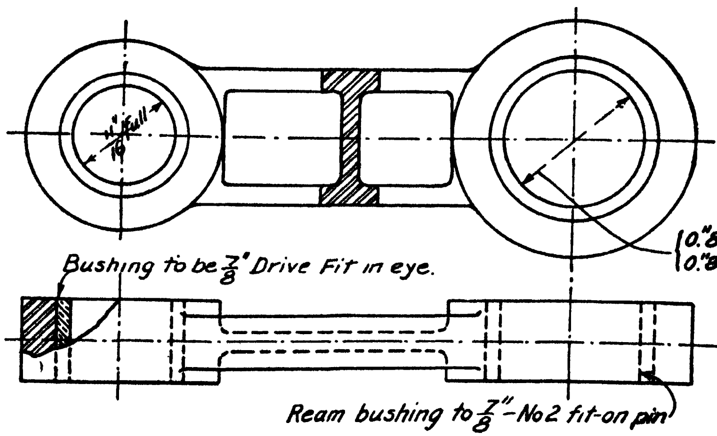


FIG. 6.

It is a common device for calling attention to a detail which might be overlooked. In this case, the bushing in this "link."

10. The Revolved Section.—This is shown on the plan above at the middle. It shows the form of the shank of this link without

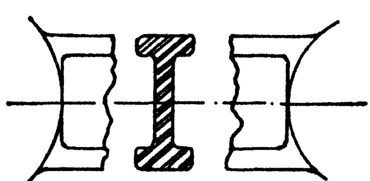


FIG. 7.

the need of a side view. On a side view, too, the form would show in broken lines. The hatching here shown is for steel. The hatching of the bushing shows a copper alloy, brass or bronze.

The revolved section is often shown in the space left when a portion of a long uniform part is broken out. In Fig. 7 the revolved section of Fig. 6 is shown as many prefer to draw it.

11. The Section on a Zig-zag Line.—The cutting plane on which a section is taken may be bent or offset in any convenient manner, but in all *complicated* cases the **path of the section** should be indicated as on Fig. 8, using line No. 5 of the Alphabet of Lines, page 36, and suitable letters to designate it.

Notice that the part of the section to the NE has been revolved until parallel to V before being projected on V, to give its true shape. See page 241, Art. 34.

In Fig. 9, a simpler case, the zig-zag line has been omitted, or it

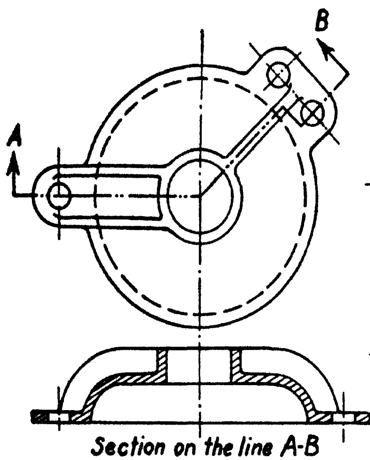


FIG. 8.

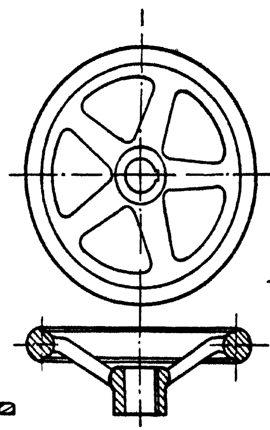


FIG. 9.

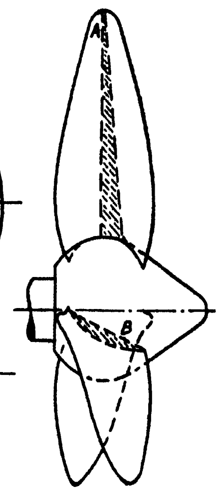


FIG. 10.

may be explained that the oblique projection of the NE spoke has been omitted and the NW spoke revolved to *W*, then projected down.

12. Section of Minimum Strength.—Sections are often taken at the weakest part of a piece in order to present to the eye the metal left for strength purposes. In Fig. 4, page 395, the full section, passing through the long slots, may have been taken with that idea. In any case it is only a new *name* not a *new* kind of section.

13. The Phantom Section.—When it is not desired to disturb the drawing of the external views of a piece, a section with broken outlines may be put on top of the drawing. Fig. 10, repeated from page 301, shows the thickness of the middle of the top blade of a

propeller as one phantom section and the thickness of the metal where the front lower blade joins the hub as another.

14. Rules for Hatching.—According to general practice:

1. Spaces for hatching lines should rarely be less than $\frac{1}{16}''$ apart. Only in very small areas is it permissible to hatch closer.

2. Use slopes of 45°, 60°, and 30° for hatching; then, if necessary, other slopes. A different angle must be chosen for each new piece of metal hatched.

3. Hatch the surface completely in pencil unless directed otherwise. If about to ink immediately, hatch in one corner only with a few lines. The choice of line and angle should be made in pencil to make clear just how the hatching in ink is to be done. Show the material of each piece by the appropriate kind of hatching as seen on page 545, except when told to "hatch for cast iron" and to designate each piece by a label or in the "bill of materials."

4. Do not hatch across lines for visible edges.

5. No part of the boundary of a hatched area is a broken line, except in the case of the phantom section.

15. Rules for Angles in Hatching.—When a piece is represented as cut in the different views so that it has a number of hatched areas on the drawing care must be taken to keep the angle of hatching everywhere the same. See Fig. 6, page 397, the hatching for steel. One can choose an angle which on the whole will give the longest hatching lines. With a constant spacing the longest lines mean the fewest lines, and fastest work.

When different pieces made of the same metal are represented in close proximity, choose a new angle for each new piece. Just as the same angle represents as far as possible the same piece, so a different angle suggests a different piece. This applies rigidly to assembled drawings.

16. Dimensioning Sketches and Drawings.—The working drawing is regularly overlaid with dimensions giving all the magnitudes essential to the manufacture of the piece.

In applying dimensions to a drawing much care must be taken to locate them so as not to obscure the drawing itself.

17. Dimensions to Locate a Plane.—A plane is usually located by giving its distance from some parallel plane.

Distances which are alike on both sides of a center line are often given as the sum of the two distances. As a particular case of this, a circle is dimensioned by giving the diameter, not the radius, whenever possible. In general, this is convenient to the mechanic.

18. Dimensioning of Cylinders.—The diameter of a cylinder is usually recorded on that view in which the cylinder appears as a circle. The position of the axis should be marked in relation to other parts of the same piece, and the location of the planes of the bases given in that view which best shows the length of the cylinder. These points are well shown in Fig. 11.

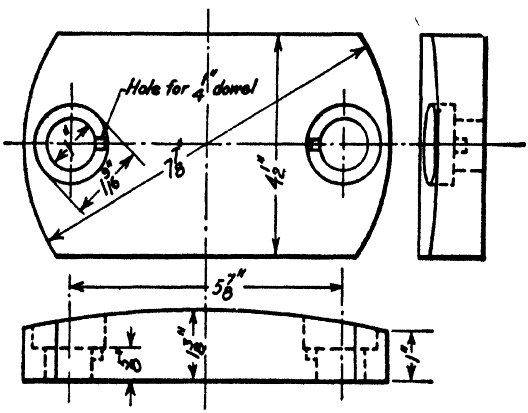


FIG. 11.

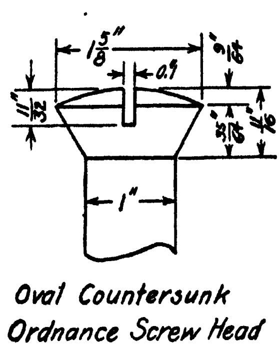


FIG. 12.

19. Dimensioning Small Arcs of Circles.—This is often done by recording the "rise of arc." The piece shown in Fig. 11 has a thickness of $1''$ at its ends and $1\frac{3}{8}''$ at its middle. The difference, $\frac{3}{8}''$, is the rise of arc. The actual curve is assumed to be an arc of a circle, in this case a circle of large radius, of undetermined value.

Fig. 12 shows a rise of arc of $\frac{9}{64}''$ in a width of $1\frac{5}{8}''$.

20. Dimensions by Offsets.—This device is resorted to for noncircular arcs as shown in Fig. 13.

21. Intersections Not To Be Dimensioned.—Lines of intersection produced by the meeting of planes and curved surfaces are not dimensioned. It is the planes and surfaces which must be defined by suitable dimensions for, if so defined, the intersections are determined by them. We saw this in drawing Sheets 9 to 15.

When machine tools are set to cut the surfaces required the intersecting lines will generate themselves. However, it is often well to show on a sketch a method of plotting a curve of intersection by sketching one cutting plane which will determine points on the curve.

22. The Dimension Line.—The typical dimension line consists of a line of *long dashes,* interrupted at one place by a blank space in which *dimension figures* are placed, and terminated by *arrowheads.*

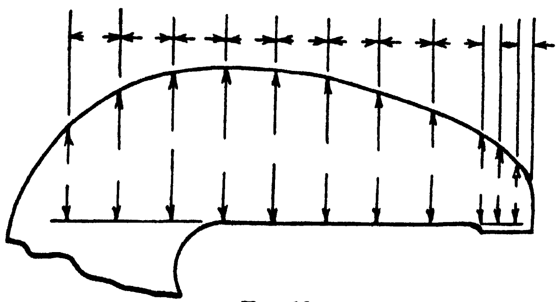


FIG. 13.

Usually the distance whose magnitude is to be recorded is the perpendicular distance between two parallel lines, as in Fig. 14.

23. In-turned Arrows for Small Distances.—When the two parallel lines whose perpendicular distance is to be recorded are close together, variations are necessary. For distances of $\frac{1}{4}''$ to $\frac{1}{8}''$ there is no room for the arrowheads to be put between the lines if the figures are placed there. They are put, then, on the outside and

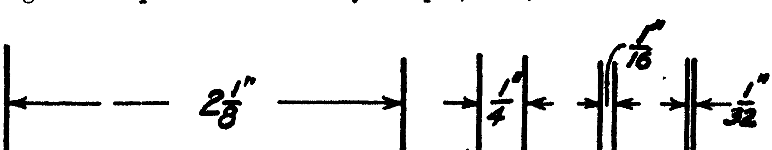


FIG. 14. FIG. 15. FIG. 16. FIG. 17.

point towards the dimension figures, not away from them. This is seen in Fig. 15.

When the space is still smaller, the dimension figures also must be put outside. There are two ways of doing this. In Fig. 16, a fine line, known as a "leader," without an arrowhead at either end

usually, leads the eye from the dimension space to some place where there is room for the figures. This line can be drawn with the ruling pen adjusted to fine line width with or without a ruling edge.

In Fig. 17 another method of recording a small dimension is shown. This method is only possible when there is no other part of the drawing near the arrowhead on one side. In that case the dimension figure can be put behind one of the inward pointing arrows, in line with it. There must be no possibility of mistaking

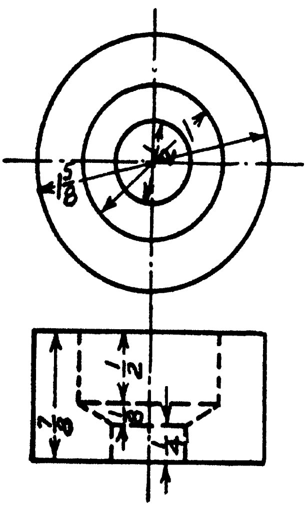


FIG. 18.

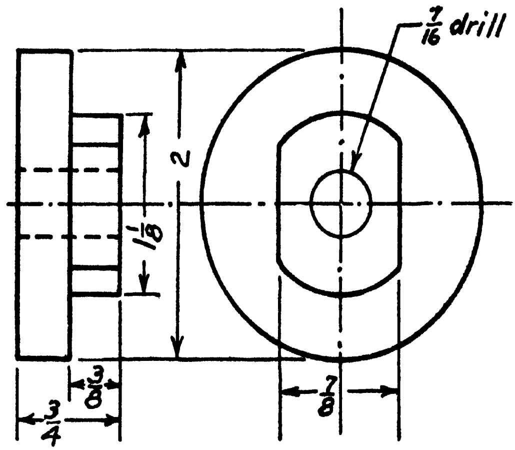


FIG. 19.

the dimension for another one to that side of the arrow where the figure is placed. In the illustration, the dimension figures, 1/32″, could not be placed behind the arrow to the *left,* for in that place the dimension would be taken for the distance between the parallel lines of Figs. 16 and 17.

24. Dimension Extension or "Witness" Lines.—Dimension lines, figures and all, are often placed over the lines of a drawing, partly obscuring it. They are better placed to one side, and the parallel lines they refer to continued beyond their natural lengths by "dimension extension lines," or "witness lines." These lines are fine full lines, also, not quite touching the object. Skill in applying

dimensions consists in picking out the best places, whether on the drawing or to one side, so that the final result is clear. **Fig. 19 is** evidently clearer than Fig. 18. Follow its method if space permits.

At the NE corner of Fig. 19 a leader carries the label "$\frac{7}{16}''$ drill" to the bore it refers to. It is a ruled line and has an arrowhead.

25. Arrowheads.—The arrowheads must be sharp (the angle at the point 60° or less), and they must end exactly on the lines, leaving no gaps. The sides of the arrowheads are usually a little concave. They should also be symmetrical.

The usual procedure is to put in the arrowheads with the sharp-pointed pen immediately after putting in the dimension lines, and then to change to a ball-pointed pen and to put in the dimension figures.

26. Dimension Figures.—These figures are written in like any other freehand lettering. Instructions for the formation of the figures is given in Part I. Since the dimension lines are not always horizontal, but criss-cross a drawing in a great many directions, the dimension figures turn with them to remain in line. They are always written, however, so that they can be read from the **south or east, never from the north or west**. When a choice of positions is possible such a selection is made as to let the figures be read from the SE in preference to SW or NE. The usual height for dimension fractional figures is $\frac{1}{8}''$. The fraction is then $\frac{1}{4}''$ high. The dimension figures must be in line with the dimension line, half above and half below it. The dividing line of a fraction *never slants*. It may be *omitted* entirely as on page 547.

For dimensions given in decimals the inch mark is over the decimal point. Thus 0.̋12, not 0.12″.

When all the dimensions are in inches the inch mark, ″, may be omitted as in Figs. 19 and 20.

There is as yet no fixed rule as to upper limit of dimensions to be given in inches. Some make it 12″, some 24″, some 72″.

27. Dimensions for Circles.—When the diameter of a circle is given, and it is always preferred to the radius when the whole circle is drawn, the dimension line should exactly cut the center of the circle and should lie in the first and third quadrants of the circle, that is to say, in the NE and SW quadrants. By observing this rule one may put in the figures to read from the SE. See Fig. 18.

Three or four diameters used as dimension lines at one center are enough. They must not be crowded in. If more circles having that center need dimensioning, carry some off by witness lines, or look for places on other views. If several circles are obviously alike one only needs to be dimensioned. In Fig. 11, page 400, one hole only is marked.

28. Dimensioning Radii.—Mechanics habitually think of sizes of cylinders by diameters, and so a dimension figure for a radius should be followed by the letter *R*, or *r*. Put no arrowhead at the center.

29. How to Mark Fillets.—A fillet which is merely the rounding of a corner is given with either *R* or *f* or with no letter at all. The location of the center is not marked. See Fig. 20. Often a notation such as "All fillets $\frac{1}{8}''$ radius" avoids repetition.

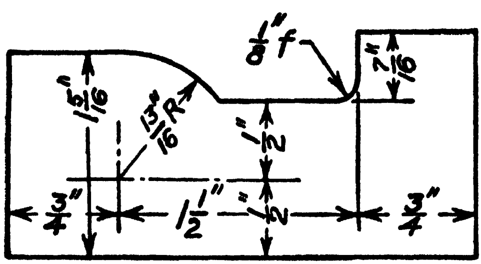


FIG. 20.

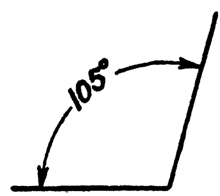


FIG. 21.

30. Arcs Which Should Be Dimensioned. When an arc is necessary for describing a contour its center should be located as in Fig. 20, but no arrowhead is used at its center. A center for such purposes is usually marked by two short intersecting lines.

31. Dimensions for Angles.—The dimension line for an angle becomes a dimension arc, struck with the vertex of the angle as center. The radius of the arc is made large enough to give room for the figures to be put in clearly. Degrees of arc are written in a curved line in a gap in the dimension arc as in Fig. 21.

To make the dimension figures read from S, E or SE, the gaps in the dimension arcs are left whenever possible in the second or fourth quadrants, that is, NW or SE quadrants reckoning these

directions from the vertex of the angle. The figures in other cases are put to read from the bottom as in Fig. 22.

Small angles may have turned-in curved arrows analogous to the variations for straight dimension lines. See Figs. 23, 24 and 25.

32. Repetition of Dimensions.—A distance seen on two views is recorded in one place only. It may be put between the views rather than on either one, as in Fig. 19. It is well to place the actual figures in the line at a place where it could be erased and changed without disturbing other work.

Symmetry of course causes much duplication of dimensions. When present it should be made evident by drawing its center line, thus saving repetition of dimension lines. One does for both sides.

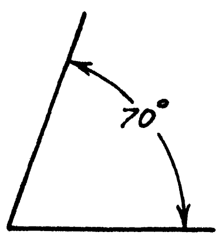


FIG. 22.

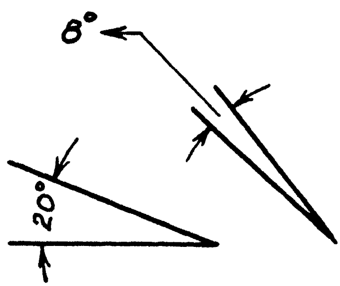


FIG. 23. FIG. 24.

FIG. 25.

33. Overall Dimensions.—These are usually of value to give an impression of size not otherwise easily derived. They give the mechanic information as to how much raw material or "stock" must be used. Of course overall dimensions must check with the summation of the part dimensions.

34. Center to Center Dimensions.—These are of prime importance. They must be accurate when work is laid out for a mistake in locating a center spreads right and left like the ripple from a stone thrown into a pond.

35. Dimensions Not to Correct Scale.—By an error in drawing some important distance may be incorrectly scaled. There may be no time for elaborate correction or for a new drawing. Or it may be that one drawing must be used to represent several different sizes.

In such case the words "not to scale" are added to the dimension in question. When there is conflict between the dimension shown by scale and that given in figures **the figure is regularly taken as having the greater authority,** unless shown to be a blunder by some other consideration. The words "not to scale" often make a mistake impossible.

36. Examples of Good Methods of Description.—The discussion previously has been in general terms. It covered the general practice of describing, by drawing and label and dimension. We now give some examples of good methods so that the student may make his own choice from a reasonable field when called on to produce working drawings.

37. Examples of Labels and Dimensions.—In Fig. 26 symmetry saves repetition of the $\frac{7}{16}''$ dimension. The labels save dimen-

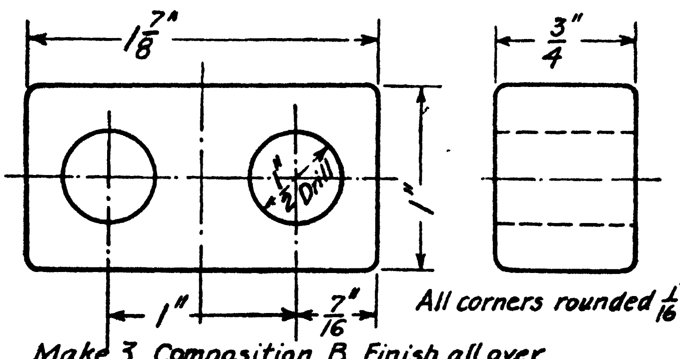


FIG. 26.

sioning small fillets, and direct machining all over. The word "drill" directs the piece to be drilled from solid stock. It is not to be cast with a core and left rough, nor is it to be reamed to exact size with extreme care.

In Fig. 27 notice that no dimension whatever is given for the curves of intersection due to the bell-shaped fillet surface being cut by the vertical sides of the diamond-shaped base. In machining the piece the curves will create themselves. They are shown to give realism to the drawing which would not be understood without

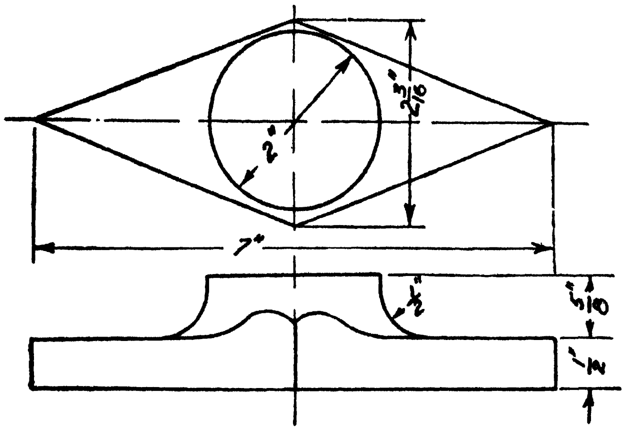

2"
7"

FIG. 27.

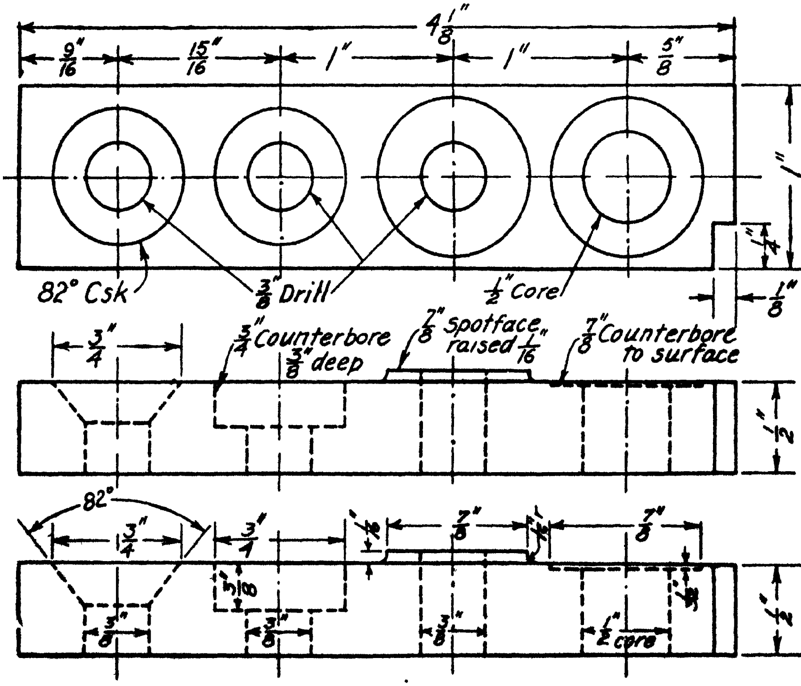

4 1/8"
9/16"
15/16"
1"
1"
5/8"
82° Csk
3/8" Drill
1/2" Core
1/8"
3/4"
3/4" Counterbore 3/8" deep
7/8" spotface raised 1/16"
7/8" Counterbore to surface
82°
1 3/4"
7/8"
3/8"
1/2" core

FIG. 28.

them. The draftsman has to know his descriptive geometry to draw it, but the mechanic has no need to pay attention to the details of the curve.

A curve produced by machining to dimensions given elsewhere is never itself dimensioned on the finished drawing.

In Fig. 28 we have a plan and two alternative front views, so as to show various methods of dimensioning. The holes depicted are a "countersunk hole," a "counterbored hole," a drilled hole with "raised spot face" and a cored hole with "surface counterbore." In the upper front view the dimensioning is done largely by labels. In the lower front view labels are not used.

Both systems are in common use.

Note the overall width, the summation of many small dimensions.

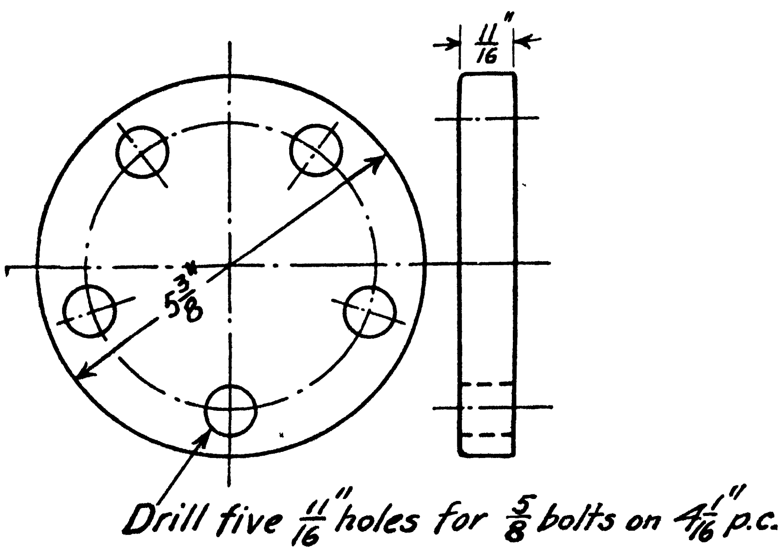


FIG. 29.

38. Dimensioning Bolt Holes.—In Fig. 29 is shown a "blank flange" for stopping off the flanged end of a pipe line with pressure of 300 lbs.

The flange before drilling needs only diameter and thickness to dimension it. All the information needed for drilling holes for bolts is given in one label, including the size of bolts to be used.

On the side view only one bolt hole has its curved sides projected from the face view. To project the others causes only confusion. The upper extremity of the "pitch circle" is projected, although no bolt hole happens to be placed at that spot.

No spacing of bolt holes is needed. Since not marked they are assumed to be equally spaced. The label is attached to that bolt hole which is located on a definite center line of the flange for beginning the drilling.

39. Clearances and Tolerances for Journals and Bearings.—Journals and bearings have been standardized with four fits; 1, "loose"; 2, "free"; 3, "medium"; 4, "close."

It is the engineer's duty to specify for any given journal what fit it should have. For an aviation engine, for example, the highest type of engineering talent has been exercised in making the proper choice for every running part and the fits noted on the working drawings.

Roughly speaking, the "loose" fit is for rugged machines like farm and mine machinery, often lubricated with heavy oil or grease. The "free" is for high-speed machinery fed with oil under pressure. The "medium" for such machines as lathes and planers. The "close" for precision machinery which is always lightly loaded. Each fit has its designed clearance, or free space to be filled with lubricant. For ease of manufacture each part in addition has its "tolerance" or limit of sizes within which it must be manufactured to be accepted. The tolerances may change the clearance from that intended but not so much so as to hurt the operation.

The first three fits are suited to quantity production and any journal should fit any bearing at random. The close fit requires "selective assembly" or a careful matching together so as to get exactly the very small clearance specified.

Such matters belong to a future field of study and, for the present, **we merely recognize the need for clearances by the use of the word "full."**

40. A Cone May Be Described by Giving the Taper, or the Slope.—The diameter at the large end of a cone is often given with a label such as "Taper 2″ per foot." This means that for every foot the *diameter* is reduced 2″.

A label on the slant edge of the cone may be such as "Slope 1 in 16" or "Slope $\frac{3}{4}$" in 1 foot." This defines the reduction in *radius* not in diameter.

Problems

(The problems which follow each chapter give the student a means of checking his understanding of the subject matter. He should try to answer some of them taken at random, and if he does not need to refer back to the text he is ready to go on to the next chapter.)

1. What methods are used in describing? Give the practical names of views when likely to differ from the standard names.
2. What kinds of sections are in common use? What is a half view and why is it used? Give the rules for hatching, and the rules for hatching angles.
3. When is the path of a section marked and how? How is the taper of a cone described?
4. What is a revolved section? Sketch two examples.
5. What is a half view? When is it used to advantage?
6. What is a partial or part view? What practical reason dictates its frequent use?
7. Explain methods of dimensioning. Give examples of labels to dimension special features in machining. What does "Slope 1 in 16" mean?
8. How can holes for bolts be tersely described in a label? What is the rule as to projecting bolt holes from the "face" view to the "side" view?
9. Show methods of dimensioning angles. When obliged to dimension an angle in the NE quadrant, from what direction should you make the figures for degrees read?
10. Sketch a bolt hole with a spotfaced surface. Sketch one with a counterbore to surface.

CHAPTER II

ELEMENTS OF MACHINE DESIGN

41. Common Pieces Already Described.—This chapter is intended to give a background of familiarity with names and functions of many small machine parts, which will be met with in engineering practice or study. Knowledge of these well-known elements of design will help one to recognize kindred pieces hereafter.

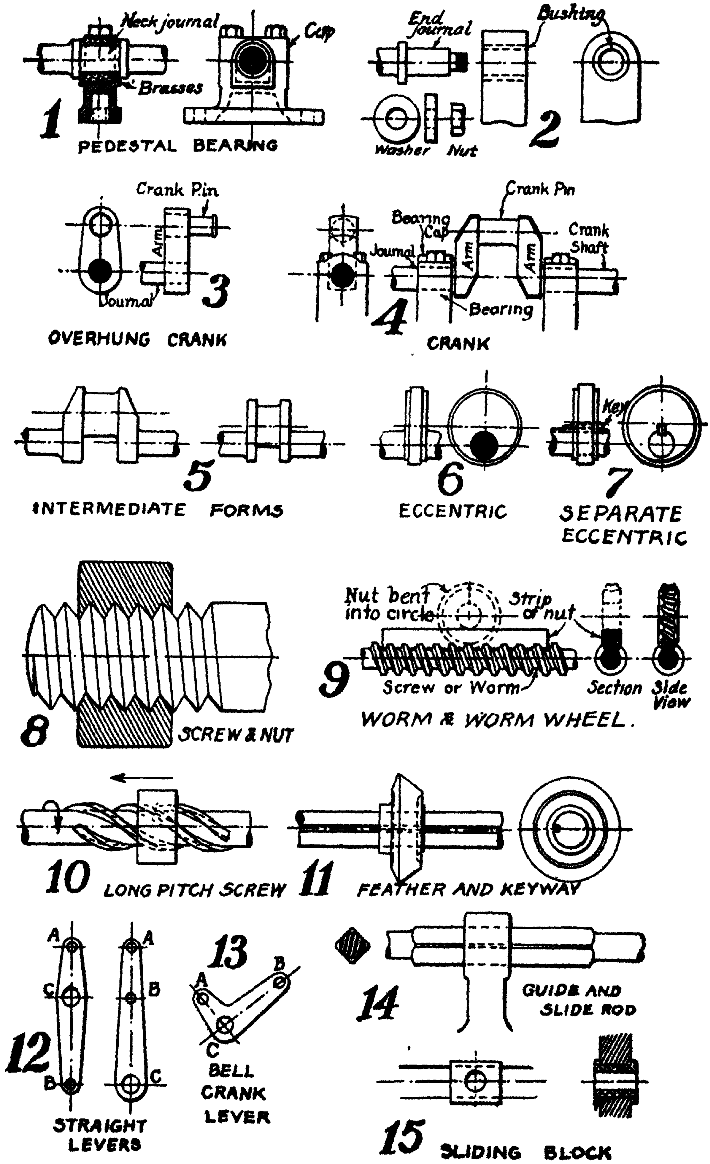
From Part I we may assume that the student knows the shapes implied by such names as "ratchet wheel," page 146; "rail section," page 156; "gear wheel," page 158; "lap joint," page 161, and "I beam section," page 173.

From Part II we may assume that he knows the shapes called the "sharp V-thread," page 299; "square thread," page 299; "propeller," page 301; "worm thread," page 302; "Y-pipe," page 354; "forked end," page 372, and "stub end," page 374.

From the preceding chapter of this part we have become acquainted with the "pipe tee," page 394; "pipe elbow or ell," page 396; the "link" and the "bushing," page 397, and the "holes," "bores," "counterbores," "countersinks" and "faces," page 407. "Clearances" and "tolerances" needed in designing and manufacturing journals and bearings must not be forgotten.

42. Other Common Pieces of Machines and Mechanisms.—In order to extend familiarity to a more representative set of machine elements, the page of small drawings (Fig. 30) is given here. Note the following points:

No. 1.—This is a typical "bearing" for a shaft. The shaft is a rotating rod. The bearing supports it. The actual part of the shaft receiving the support is the "journal." A neck journal must have its bearing made in halves. The part which can be unbolted and removed is the "cap." The actual pieces prepared to receive



Neck journal
Cap
Brasses
1
PEDESTAL BEARING
End journal
Bushing
Washer
Nut
2
Crank Pin
Arm
Journal
3
OVERHUNG CRANK
Crank Pin
Bearing Cap
Crank Shaft
Journal
Arm
Arm
Bearing
4
CRANK
5
INTERMEDIATE FORMS
6
ECCENTRIC
Key
7
SEPARATE ECCENTRIC
8
SCREW & NUT
Nut bent into circle
Strip of nut
Screw or Worm
Section
Side View
9
WORM & WORM WHEEL.
10
LONG PITCH SCREW
11
FEATHER AND KEYWAY
A
C
B
A
B
C
12
STRAIGHT LEVERS
13
A
B
C
BELL CRANK LEVER
14
GUIDE AND SLIDE ROD
15
SLIDING BLOCK

FIG. 30

the rubbing of the journal are two bearing "brasses." These are generally of bronze, not brass, and often are lined with anti-friction metal. Brass is an alloy of copper and zinc. Bronze, an alloy of copper and tin. Anti-friction metal, an alloy of tin and antimony, with a very little copper. In brass and bronze, copper is the chief constituent, in anti-friction or "white" metal, tin.

No. 2.—This bearing is for an "end journal." It does not need to be made in halves. A "bushing" of bronze is provided to give a proper wearing surface. The end journal, when in place, is held from slipping out by a "loose collar" or "washer," which is secured by a nut.

No. 3.—A "crank" is a part of a shaft bent out of line so that force applied to it may rotate the shaft. This crank is a built-up crank, having separate "crank arm" and "crank pin," the arm being shrunk on to both pin and crank shaft by heating it until large enough to slip over them. When cold it grips very securely. Close to the arm the shaft should have a journal and a bearing to support it.

No. 4.—This crank occurs in the middle of a length of shafting. Shaft, crank arms and crank pin are all forged as one piece of metal. Journals are needed close to the crank arms on each side.

No. 5.—These are cranks whose pins are so large as to partly come in line with the main shaft.

No. 6.—In this the crank pin is so large that it takes in the shaft diameter completely. This is an "eccentric." It is forged in one piece with the shaft and does not weaken it. The eccentric acts like a crank and is called "mechanically equivalent" to a crank.

No. 7.—This is a separate eccentric or "eccentric disc," slipped on over the end of the shaft and kept in place by a "key," as shown. "Keyways" are cut in both shaft and eccentric to accommodate the key. Eccentrics are often made in two halves secured together by bolts. It is not always possible to slip the eccentric on over the end of the shaft.

No. 8.—This is the ordinary "screw" and its "nut." The triangular form of screw thread is especially adapted to fastenings. The "pitch" of a screw is the distance from a point on a thread to the corresponding point on the next turn.

No. 9.—This is the "worm" and "worm wheel." The worm is a screw thread, generally of the form of that in Part II, page 302. The worm wheel is a long strip with threads fitting the worm, a nut for it, bent into a circle. The worm nearly always turns the worm wheel. Friction prevents the reverse motion unless the pitch is very long. The worm thread is often called the $29\frac{1}{2}°$ thread, from the angle between the sides of the groove. The "depth" of the groove is half the "pitch."

No. 10.—This is the "long pitch screw." In this form the axial motion of the nut which fits it may cause the screw to rotate. In short pitch screws rotation of one piece causes relative axial motion and friction prevents the reverse operation.

No. 11.—This represents a "bevel friction gear," or similar piece which receives rotation, and a shaft which can slip freely through the bevel gear lengthwise, but must rotate with it on account of the projecting "feather" on the inside of the bevel gear, which fits in a keyway or long slot cut in the shaft or "spindle." If the feather is a separate piece of metal sunk partly into the bevel gear, it is a key. It is not, however, a tight key like that in *No. 7.*

No. 12.—These two "straight levers" have each two "working points," *A* and *B,* to which rods are secured and a "fixed point," or fulcrum, *C.* *C* is a hole which passes over a fixed "journal pin" and allows the lever to turn about it. The pin or "pivot" may be very similar in shape to the end journal in *No. 2,* with washer and nut, but in this case the hollow cylinder turns and the solid cylinder is fixed in place.

No. 13.—A bent lever is called a "bell crank." The lines of action of the rods secured at *A* and *B* are not parallel. In straight levers the rods should be parallel or nearly so.

No. 14.—This fixed "guide" is intended to permit axial sliding to the "slide rod," but no rotation. The rods which move valves for admitting steam to steam engines are sometimes designed in this way. In that case the rod is called a "valve stem."

No. 15.—A "sliding block" slips in a straight groove or one in the form of an arc of a circle. Usually some "connecting link" or rod is secured to the block by a pin which passes through it, or the block has two "journal pins" projecting, one on each side, to which the forked end of the rod is pivoted.

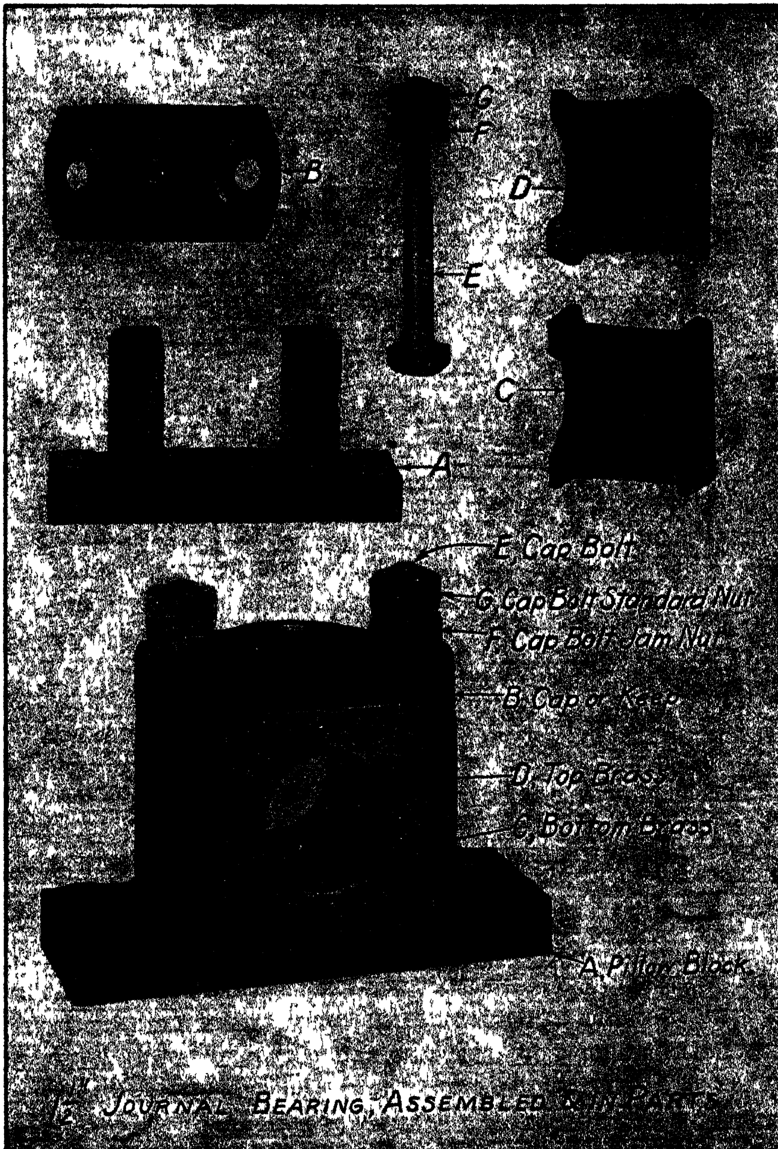

G
F
B
D
E
C
A
E, Cap Bolt
G, Cap Bolt Standard Nut
F, Cap Bolt Jam Nut
B, Cap or Keep
D, Top Brass
C, Bottom Brass
A, Pillow Block
12" Journal Bearing, Assembled

FIG. 31.

43. Parts of a Journal Bearing.—In Fig. 31 we see photographs of an assembled journal bearing and of its separate parts.

Note the names given. The piece, *A,* the *"Body"* or *"Pillow block"* shows well the raised spot face and the piece, *B,* the *"Cap"* or *"Keep"* shows the flush spot face or surface counterbore.

These two pieces are castings and the natural surface of a casting is too rough to afford a smooth seat for the under surfaces of the nuts to bear against when screwed tight. Hence the spot faces.

The square-headed bolt, *E,* has a standard nut, recognized because nearly as thick as the bolt is itself, and a shallow nut, known as a *"Jam Nut."* This nut should go on first when bolting up the work.

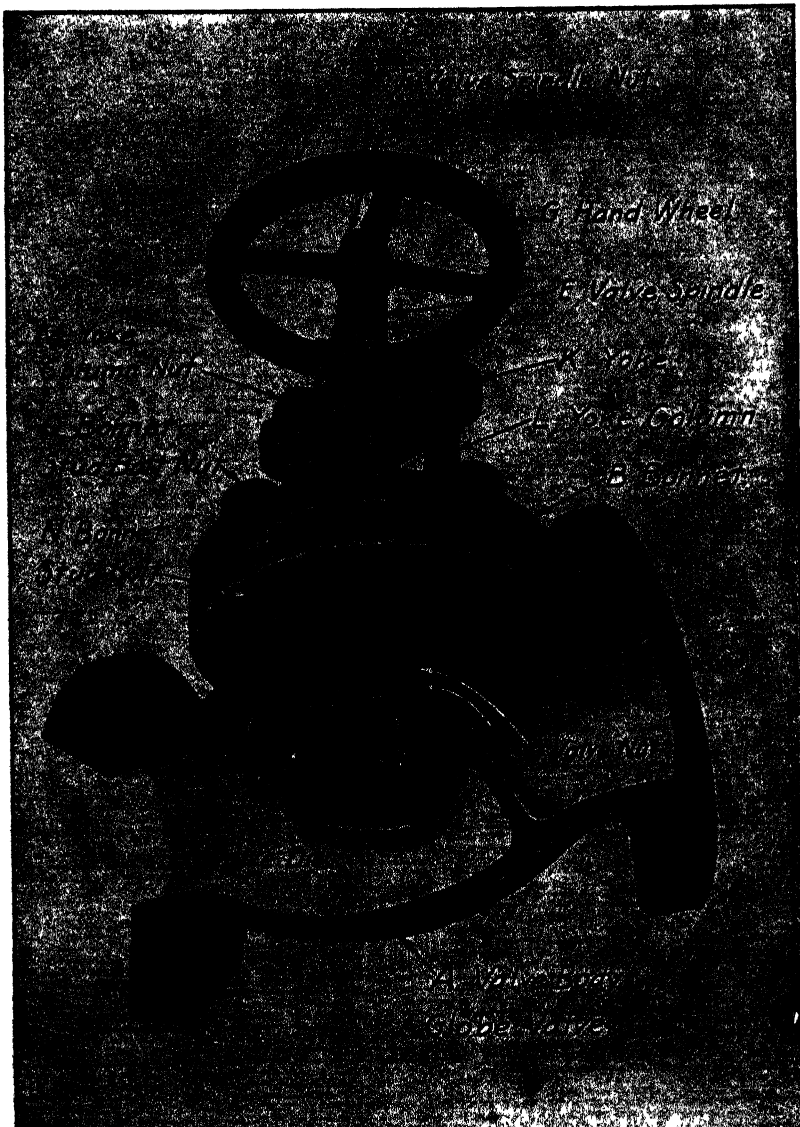
The *"Brasses,"* *C* and *D,* nearly alike, differ in that the top brass *D* has an oil hole leading through it to a shallow oil grove, not quite so long as the actual journal it fits around.

44. Parts of a Valve.—Figs. 32 and 33 are from photographs of two common styles of flanged pipe valves. The first is the *Globe Valve.* The second is an *Angle Valve.* Whether either one is a *Stop Valve* or a *Check Valve* (strictly a Stop-Check Valve), will depend on what style of *Valve Disc* (*C* or *C′*) and *Valve Spindle* (*E* or *E′*), will be found when it is opened up.

The *Body, A,* of the globe valve suggests a pipe tee when by itself. The flange for the side outlet is not for a branch pipe but is the opening in which are inserted the actual valve disc and the spindle to which it is loosely shackled and by which the valve disc is operated.

The *Bonnet, B,* covers this opening, which is usually up, getting its name thereby. It is held in place by *Bonnet Stud Bolts, N,* and their nuts, *O,* which must make tight the joint between body and bonnet against any leakage.

The *Yoke, K,* which binds together at their top two *Yoke Columns, L,* much as the yoke of old bound together two oxen, is threaded and the valve spindle screws through it. When the *Hand Wheel, G,* is turned the spindle will screw up or down through the yoke and operate the valve disc as it does so. The spindle must pass from outside to inside where pressure may be very great. To avoid leakage around the smooth neck of the spindle we have a


G Hand Wheel
E Valve Spindle
K Yoke
L Yoke Column
B Bonnet
A Valve Body
Globe Valve

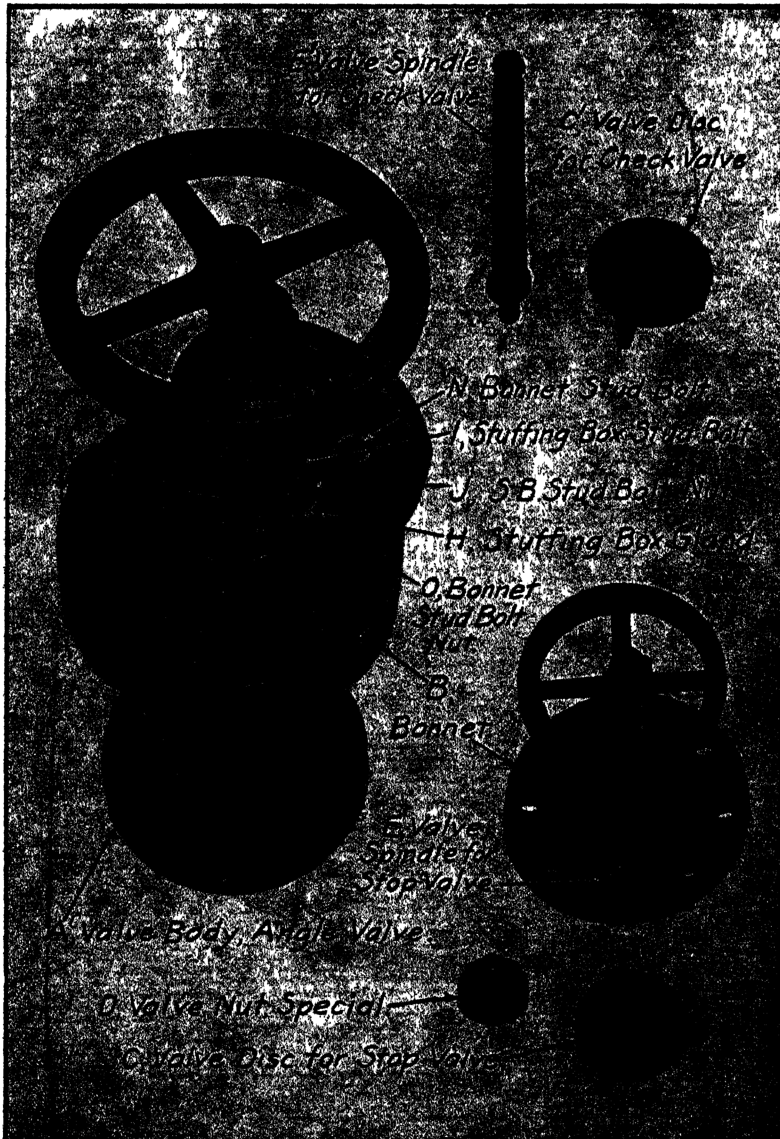

Valve Spindle
for Check Valve
C Valve Disc
for Check Valve
N Bonnet Stud
I Stuffing Box Stud
J S.B Stud Bo
H Stuffing Box
O Bonnet
Stud Bolt
B
Bonnet
E Valve
Spindle fo
Stop Valve
A Valve Body, Angle Valve
D Valve Nut Special
C Valve Disc for Stop

FIG. 33.

combination consisting of a counterbore in the bonnet known as a *Stuffing Box*, a *Stuffing Box Gland, H,* which presses loose woven *Packing* tightly in the box, and *S. B. Stud Bolts, I,* and *Nuts, J,* to supply the pressure needed to make the packing tight.

Problems

11. Define a journal; a bearing; a bearing brass; a bushing; a crank, an eccentric.

12. Define a worm wheel; a feather; a key; a keyway; a lever; a bell crank; a long pitch screw.

13. Name the parts of a journal bearing and give the function of each part.

14. Name the parts of a valve and give the function of the valve stem, yoke, bonnet and hand wheel.

15. What parts of Fig. 33 should be assembled with the globe valve of Fig. 32 to make it a globe stop-check valve?

16. What is the stuffing box and what accessory parts are needed to pack the stuffing box?

17. Sketch a worm and worm wheel.

CHAPTER III

SKETCHING IN ENGINEERING DRAWING

45. A Sketch Usually Precedes a Drawing.—When called upon to make a drawing, especially one of an unfamiliar object, a draftsman always feels a need to jot down in pencil some preliminary trial arrangements. By these trial sketches he gets his mind in focus and gains, in advance, some idea of the finished drawing he expects to produce.

A sketch, even of a very fragmentary kind, is a valuable preliminary to the making of a precise drawing.

The great majority of practical drawings are preceded by some kind of a sketch. We have not felt the need of sketches in executing the drawings of this course, ere now, simply because the exact location of objects, and the exact number of views required, have been minutely specified in each case.

It is time now to widen the point of view, and to consider that the draftsman must not only execute the views required of him, but, when given some actual mechanical object, or the idea of one, he must be able to decide what views are the most desirable to convey directly, and exactly, the geometrical shape of the object at hand.

As an aid to deciding on the best set of views, sketches are invaluable. They save much laborious work which might go for naught if the first choice of views should prove an unfortunate one.

46. Sketches as Informal Drawings.—It is not the "rough sketch," such as may suffice to fix the ideas of the expert draftsman when dealing with some new design, that we intend to deal with here. We deal with sketches which may be regarded as informal drawings. In them there is nothing intentionally "rough." They are *careful sketches,* and they are true mechanical drawings in which, for convenience, the use of instruments has been reduced to a minimum.

Sketches of this more finished type often serve in place of formal

drawings. **All the rules of projection are in force** as in the formal drawings, although observance of them is by careful judgment by "eye" rather than by the use of T-square and triangles. Precision in size of parts is obtained by recording dimensions profusely, rather than by drawing the parts precisely to scale.

A sketch is not complete without a full set of dimensions recorded on it.

47. Value of Sketching to Engineers.—During the period of instruction of a student engineer, the ability to make a good sketch is an important aid to the study of engineering in all its branches. In the study of the actual machinery with which the engineer must become familiar, sketches serve to fix the shapes in the mind and they serve as illustrations and records of work done. Midshipmen are required on their cruises to make sketches of machinery in the engine room as a means of familiarizing themselves with naval machinery. In the study of machinery from text-books the illustrative drawings can best be fixed in mind by reproducing them as sketches, and in recitations such sketches are constantly called for.

After graduation the ability to make good sketches of machine parts is an important factor in a naval officer's professional equipment, as it is of all engineers. Those performing engineering duties, are constantly called upon to make sketches of broken parts, or of new fittings, or of suggested alterations to machinery. Such sketches must frequently be made in places, and under conditions, precluding the use of instruments, yet if carefully made they enable repair work to be commenced while a ship is still at a distance from a base and separated from a repair ship.

Attempts to get fittings prepared in advance, in order to shorten a ship's overhaul period, will fail utterly if the sketches provided to show the nature of the work are vague, inexact, or ambiguous. Such sketches lead only to prolonged correspondence and delay, to the exasperation of all concerned.

48. Aim and Plan of the Sketching Course.—A progressive course in mechanical sketching becomes an important part of the drawing course at this place.

Beginning with simple objects, some 16 to 20 models of small machine parts are served out in succession to the students. From

each a sketch is required, so precise that from it a mechanic could reproduce the original piece. The student himself is to decide in each case the best views to show, the sections to make, and the dimensions needed for constructing the piece.

When some of the models have been sketched they will be removed and each student required to make, from his sketches, finished working drawings, or finished scale sketches, of such of the pieces as may be selected. This is done again later, and again for examination purposes. While making sketches always think ahead and imagine yourself attempting to draw the objects from your sketches alone. Test your work as to the sufficiency of the dimensions or of the views selected in that way.

49. What Constitutes Precision in Sketching.—While the lines of a sketch are not of that degree of precision which is a feature of mechanical drawing, they should be sufficiently accurate, in location, in straightness, or in degree of curvature, to leave no element of doubt about the meaning of the line. If the sketch is laid aside for a long time it should still be possible for any draftsman to take it up and make a drawing from it. For this reason the **pencil lines should follow the alphabet of lines**, on page 36. In pencil, however, no distinction in thickness of line is attempted.

On a sketch, lines are located "by eye," *i.e.*, by an act of judgment as to position relative to one another. The **exact distances**, however, must be measured and recorded. A sketch is considered exact when lines are approximately in correct position and dimensions are exact.

50. Knowledge of Shop Practices Necessary.—In order to instruct mechanics how to make the pieces described by sketches or drawings, the draftsman must know a great deal about the manufacture of metal objects. Knowledge of the qualities of metals, shop methods and common details of design will help any student in his future studies as well as any engineer in practicing his profession.

This book seeks to give a foundation on which to build up such knowledge, as well as to teach drawing.

51. Eye Sketches.—Sketches differ in the degree in which they observe the formal rules of projection. The type of sketch we deal

with now is that in which all distances are judged by eye. These may be called "eye sketches," and may be executed either on unruled paper or on coordinate paper. Coordinate paper, also called cross-section paper, is ruled in little squares and comes in many sizes and kinds. When used for eye sketches the ruling serves chiefly as an aid to the projecting of points from view to view, and to the production of straight lines in general.

Eye sketches may be described as approximately full size, or half size, as the case may be, but they have no exact scale.

52. Scale Sketches.—Another type of sketch is that of "scale sketches," so called from the fact that they are almost exactly to scale. These sketches are in reality a step between eye sketches and pencil drawings. They are made on coordinate paper and the unit of the coordinate paper represents some linear unit. They are generally made from eye sketches, not directly from the machinery itself, and are so accurate that tracings in ink may be made over them. Thus a scale sketch is a substitute for a pencil drawing and should be considered as a valuable labor- and time-saving device.

The compass is used in making scale sketches for the principal circles, and other instruments when convenient. If executed on *accurate* coordinate paper it is one of the best methods of producing quick results on a "hurry job." We regard scale sketching as a substitute for pencil drawing with full set of instruments, and will make use of it at appropriate times.

53. Sketching by Eye on Coordinate Paper.—The first sketches in the course are of this type. The only instrument used is the sketching pencil, a medium hard pencil, say H or 2H. The sharpening for the pencil is the cone point, slightly rounded. The 4H pencil, used for drawing, makes too light a line to predominate over the lines of the ruled paper.

No straightedge should be used. Lines must be carefully drawn, freehand, vertical and horizontal lines following the lines of the cross-section paper, or parallel to them.

Distances should be judged by eye. and not determined by counting small squares, except in the plotting of circles.

54. Plotting and Sketching Circles on Coordinate Paper.—Circles may be plotted by locating a fair number of points and

sketching a line through them. For this we make use of the properties of right triangles. For example, a circle of radius 5 is easily described on coordinate paper. We know that the triangle whose sides are 5, 4, and 3, is a right triangle, since $5^2=4^2+3^2$. Choosing a point of intersection of lines of the ruling as center, we count off 5 units in each direction for the vertical and horizontal diameters. We then interpolate two points in each quadrant by counting 3 in one direction from the center and 4 at right angles to it. We thus obtain the points shown on Fig. 34. The right half of that figure

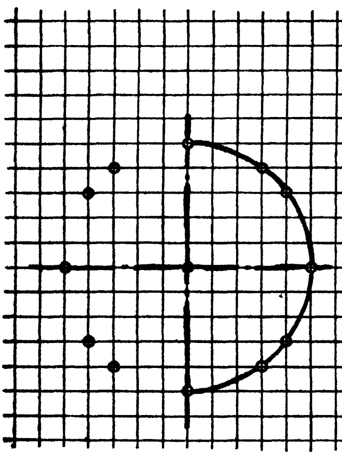


FIG. 34.

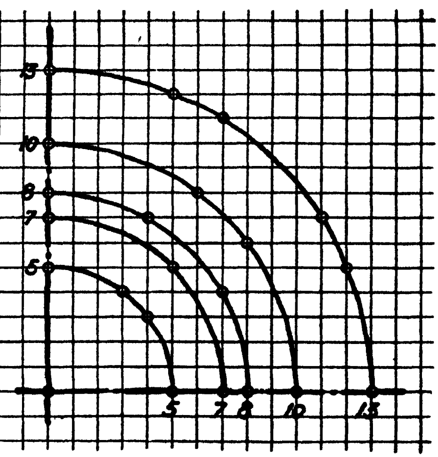


FIG. 35.

shows the circumference sketched in. This process is applicable also to circles of radius 10, or any other multiple of 5. The numbers corresponding to 3 and 4 are multiplied up in the same way. For the radius 10 they are 6 and 8, of course.

Another right triangle whose sides are all integer numbers is that of 13-12-5. $13^2=12^2+5^2$. In addition to two points in each quadrant obtained by measuring 12 along one diameter and 5 along the other, we may also measure 11 along one diameter and 7 along the other. For $13^2=11^2+7^2$ (very nearly). The plotting of such a circle, one quadrant only, is shown in Fig. 35.

Fig. 35 also shows quadrants whose radii are 7 and 8, plotted

from the approximations, $7^2=5^2+5^2$ (nearly), and $8^2=7^2+4^2$ (nearly). The series of quadrants shown in Fig. 35 enables us to draw circles of radius 5, 7, 8, 10, 13. Since, in sketching, sizes need to be only approximately correct, one can generally select a size of circle from this list (and its multiples) to suit any size wanted.

55. Sketching on Unruled Paper.—This is naturally more difficult than sketching on ruled paper. Great care must be taken to make vertical and horizontal lines straight and true, and to make the views project one to the other. It becomes more difficult to plot

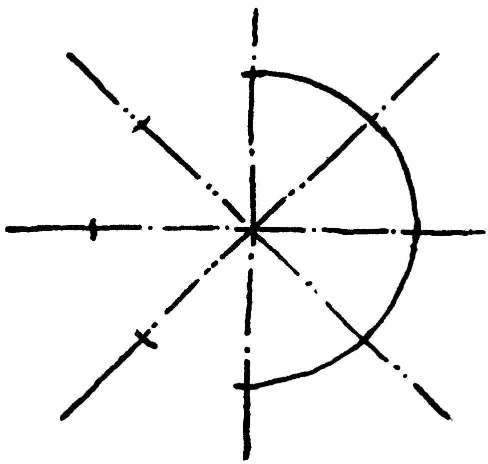


FIG. 36.

circles with sufficient accuracy to satisfy the eye. A good way to do is to draw the horizontal and vertical center lines first, and to lay off on them, by eye, in all four directions from the center, the radius of the circle. The next step is to draw 45° diagonal lines, as in Fig. 36, and to lay off the radius on these also. Not until the eight points have been plotted and short tangents passed through them, is it advisable to begin sketching in the actual circumference. This has been done for the right half of Fig. 36.

When a piece to be sketched is of the shape of a disc, there will be one view which is principally a large circle. Draftsmen often describe such a large circle by holding the pencil nearly perpendicu-

lar to the paper with the hand held rigidly and resting on the nail of the little finger, so that that nail alone touches the paper. The left hand then turns the paper under the pencil. A very good large circle may be thus described with no flaw save a slight lack of exact junction of the end to the beginning. This is easily remedied.

The difficulty in thus using the hand as a compass is that the location of the center is more or less a matter of chance. The center lines must be put in afterwards. It is used, then, for the initial circle of a sketch, and if smaller concentric circles are required, they are described by paralleling the original circumference at the required distance.

The leaves of the loose-leaf sketch book lend themselves to this process of "spinning the paper." Midshipmen when at work making eye sketches are expected never to use a compass for any circle, large or small. The first freehand circles may be rather defective but to use instruments defeats the aim of sketching and leads to no future improvement.

56. Steps in Producing a Finished Sketch.—If a small piece of machinery, or a model built to its shape, is issued to you with direction to make a "working sketch" the following procedure is to be followed:

(1) Choose a clean sheet of the sketch book. At first you will be directed as to whether to take a plain sheet, a sheet ruled in inches and eighths or an isometric sheet. Later on you make your own choice.

(2) Assuming that a plain sheet has been chosen or ordered, estimate the size of the sketch needed and proceed to select the views and sections. Follow the dictates of your judgment, basing it on the procedure in Chapter IV, and the background of methods of description shown in Chapter I. Execute the orthographic projection portion of your sketch, leaving a fair space between views so that dimensions may be applied where they will not obliterate the views. Include center lines in this work.

(3) Proceed to apply dimension lines to the sketches following the methods shown in Chapter I. The lines can be put in place before any dimension figures are inserted.

(4) Measure the model and insert the correct figure in the di-

mension lines, as fast as determined. To measure properly we have in the drawing outfit three instruments which have not been described hitherto, and will now be described.

57. Folding Foot Rule.—This box-wood, brass-bound scale folds to a length of 3″. A two-foot instrument of the same type is the standard carpenter's rule. It is useful in measuring parts of machines and is graduated to eighths, on the outside, and to sixteenths, on the inside. It may easily be used to measure thirty-seconds. The triangular scale is too delicate to use on machinery, for its edges must be kept from chance of injury. The foot rule is not a drawing board instrument at all, nor are the two calipers which follow. They are used more for the sketching than for the drawing and are for taking dimensions from existing work. Fig. 37 shows the two-foot rule.

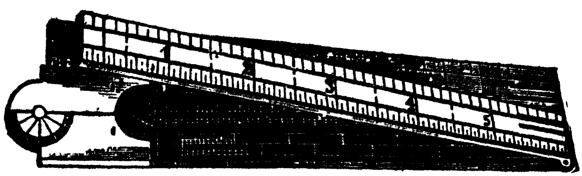


FIG. 37.

58. Outside Calipers.—These calipers, Fig. 38, are a form of dividers, rugged, and little subject to injury. They are used for taking measurements from machinery. The legs are bent and the joint is very stiff. The aim is to adjust the calipers to fit a piece of machinery, as for example, a cylinder, and then to apply the calipers to the rule to make a reading of the distance between the legs. By reason of the curved legs, the instrument may reach over obstructing parts to places where the straight rule cannot be applied.

Make the rough adjustment of the calipers by forcibly opening the legs to the extent judged correct by eye, using one hand to each leg. Make the fine adjustment by tapping against a hard resisting object. If the coarse adjustment has left the legs too far apart, grasp one leg at *b* by two fingers, and tap a table-top or a metal part of machinery, so that the blow is felt at *a* on the opposite leg. A smart tap closes the instrument a given amount, and by

practice one learns the result of a blow of a given force. It is thus possible to make gradual, slight changes until exact results are attained. If the jaws are too close together, hold the leg *b* and strike the tip *c* of the other leg against an unyielding object in such a way as to open the calipers.

59. Inside Calipers.—These are shown in Fig. 39. They differ from the outside calipers in having straight legs with out-turned toes. The instrument is adapted to measuring the width of holes or gaps in solid objects, rather than the widths of the solids them-

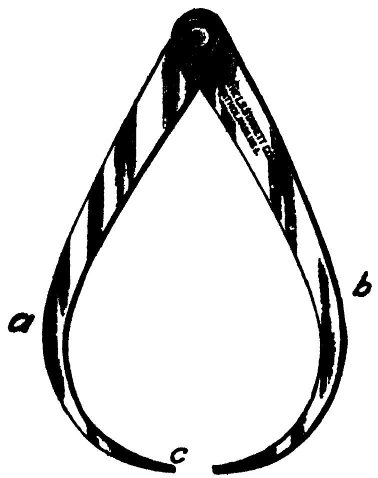


FIG. 38.

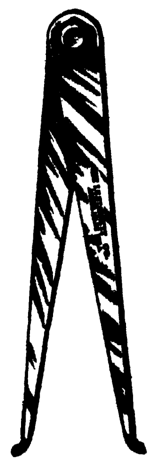


FIG. 39.

selves. For example the diameter of a bore hole is so measured. When the adjustment is made and corrected by tapping in a way similar to the adjustment of the outside calipers, the actual reading is taken from the foot rule by measuring the distance from toe to toe.

Problems

18. What officers are especially called upon to make mechanical sketches? What determines whether a dimension is needed or not? When is a sketch considered a precise and accurate one? How does a scale sketch differ from an eye sketch? Sketch on cross-section paper, or on a hand-made imitation of it, a circle of radius 5.

19. Sketch a circle of radius 13 on a cross-section paper. In each quadrant there are two points which are interpolated as the result of the 13-12-5 right triangle. It is not necessary to remember the calculation for the two additional approximate points. They are between the exact points and are easily detected by the eye.

20. Sketch a circle whose radius is 8. If the approximate equation has been forgotten, reproduce it by trial from the squares of the numbers less than 8. Show how to sketch a circle on unruled paper, using eight points.

CHAPTER IV

THE ELEMENTS OF ISOMETRIC SKETCHING

60. Isometric Projection.—There is one special branch of Orthographic Projection which is of peculiar value for representing forms which **consist wholly or mainly of plane faces at right angles to each other.** Ordinary orthographic views are projections upon planes parallel to the principal plane faces of the object. If, however, instead of the regular planes of projection, the object is projected upon a new plane of projection, making the *same angle with each of the regular planes,* an entirely different result is obtained, called an *"isometric projection."* This view has the useful property that it has all the air of a perspective and may, with certain restrictions, be used alone without other views as a full representation of the object.

Objects having a few beveled edges or a few cylindrical parts, yet mainly of plane faces at right angles, can be shown in isometric form. Too many bevels or cylinders spoil isometric representation.

This chapter seeks to explain when and how to make isometric sketches from which orthographic views could be drawn.

61. Isometric Sketches of Rectangular Objects.—Figs. 40, 41 and 42 show a block having a lengthwise groove in three positions. At first it is held as it would be for an orthographic projection as for example a projection on V, a "front view."

In Fig. 41 it is turned 45° about a vertical axis. The edge *ad* is parallel to the picture plane. *ab* and *ac* are inclined 45° and are foreshortened to 70.7 per cent of their true length.

In Fig. 42 it is tilted so that the top comes forward and the bottom recedes. The axis of this tilting is a horizontal line parallel to the paper. The angle of tilting is a trifle over 35°. During this tilting *d* is receding and so the length *ad* is shortening. *b* and *c* are approaching and *ab* and *ac* are lengthening.

When tilted exactly right, 35° 16′ to be exact, *ab, ac* and *ad* are

all foreshortened exactly the same amount. They project about 83% of their true length. Moreover, the angles between them are now all 120°. The term isometric comes from the equal treatment

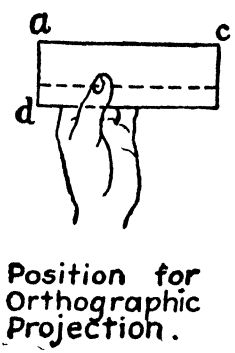


FIG. 40.

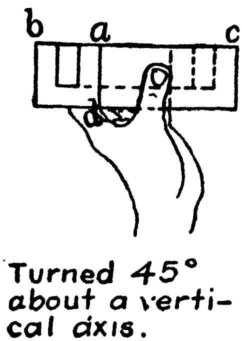


FIG. 41.

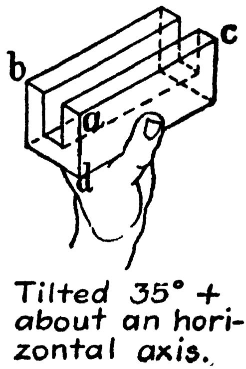


FIG. 42.

of the three directions which are all foreshortened alike and can be measured, therefore, to the same scale. "Iso" in Greek means "equal."

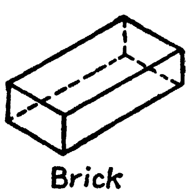


FIG. 43.

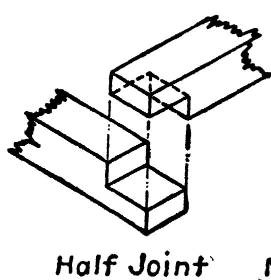


FIG. 44.

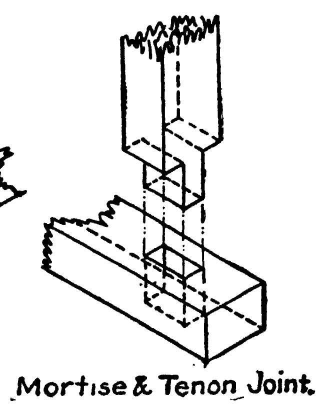


FIG. 45.

Figs. 43, 44 and 45 are typical objects for isometric representation. As sketches they are easily understood. If drawn accurately the scale could be used along all the edges and could check up any such dimension.

62. Isometric Axes.—The three directions which in Fig. 40 were parallel to the axes of X, Y and Z, and which in Fig. 42 make equal angles with the line of sight are called the ***isometric axes.*** In this term the word axis means a direction, not a particular line. One of the three isometric axes is a vertical line and the others make 60° angles with it.

If the turning of 45° and tilting of 35° are always taken in the standard way, as described, the regular x coordinates can be plotted, from any point selected as an origin (point c on Fig. 46), down to the left. The y coordinates can be plotted up to the left, and the z coordinates vertically downward.

63. Isometric Paper.—Paper ruled in the direction of the isometric axes is called isometric paper, and is of great assistance in making isometric sketches. The lines divide the paper into small equilateral triangles.

In sketching, the sides of these equilateral triangles are taken to represent unit distances, exactly or at least approximately. Thus, if the model shown in Fig. 42 is a block 3″×3″×8″, with a 2″×1″ groove lengthwise along one face, some point a on the paper is selected, and from it distances are taken along the isometric axes, so that each unit space represents one inch.

From a three units are counted vertically downward, eight up and to the right, and one unit, followed by a gap in the line of one unit, and then a second unit, up to the left. Thus all lines of the sketch follow the ruled lines as long as the dimensions of the model are in even inches.

An isometric sketch made in this manner, particularly if spaces have been exactly counted off according to the dimensions of the piece, is practically an isometric drawing. If fully dimensioned, a sketch on plain paper proportioned by the eye is nearly as good as one in which spaces are counted exactly. Such sketches serve all purposes, though of course more difficult to make than those on isometric paper.

64. Non-Isometric Lines in Isometric Sketching.—Objects which have a *few* faces and edges oblique to the principal plane faces may still be shown by isometric sketching. In such cases it is always well to circumscribe a set of rectangular planes about the

oblique parts of the object to aid the imagination. Construction lines should be used for this purpose. In using isometric paper this squaring up is done by the lines of the paper.

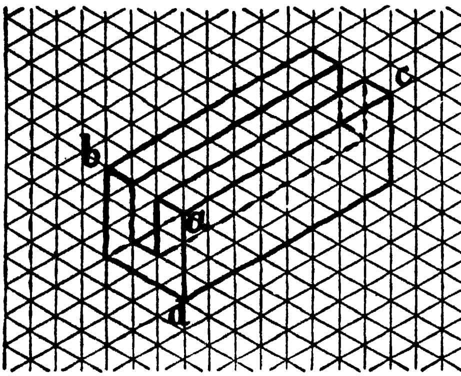


FIG. 46.

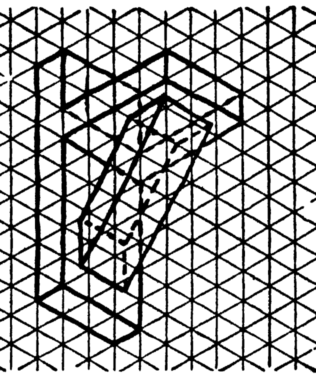


FIG. 47.

Figs. 47, 48 and 49 are examples of objects having inclined lines and faces, which are squared up by construction lines.

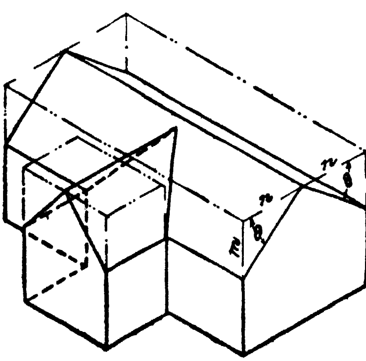


FIG. 48.

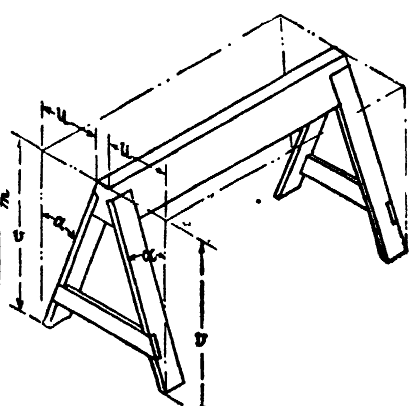


FIG. 49.

65. Angles in Isometric Sketching.—In isometric sketching angles do not, as a rule, appear of their true magnitude. Thus the 90° angles on the faces of the brick appear in Fig. 43 as 60° or

120°, but not as 90°. In general, the lengths of oblique or inclined lines depend on position, and are not subject to measurement by scale.

The lines which square up oblique parts are useful in giving the *tangent* of the angle of an oblique surface. Thus in Fig. 49, the angle α differs in reality from the angle as it appears in either place marked, but the *tangent* of α is $\frac{u}{v}$. In Fig. 48, $\theta = \tan^{-1}\frac{m}{n}$. In practice angles are often given by their tangents. Thus the slope of a roof is given as "one in two" or the gradient of a railroad as "three per cent."

66. Cylindrical Surfaces in Isometric Sketching.—In orthographic drawings circles appear commonly on planes parallel to the three planes of projection. To illustrate the position and appear-

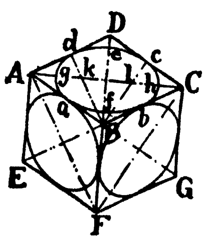


FIG. 50.

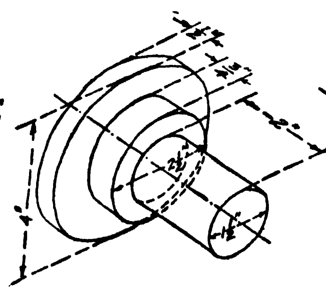


FIG. 51.

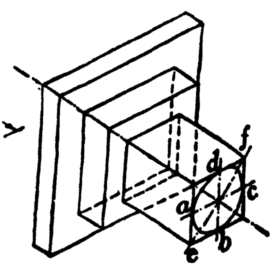


FIG. 52.

ance of circles in isometric drawing in the three typical cases, Fig. 50 represents the isometric sketch of a cube, having a circle inscribed in each square face.

Each of the faces of the cube is perpendicular to the isometric axis given by the intersection of the other two faces. Thus the square *ABCD* is perpendicular to the edge *BF*. The circle *abcd*, inscribed in the square *ABCD*, appears as an ellipse, whose minor axis, *ef*, lies on the diagonal *BD* of the square, *BD* appearing as a continuation of the edge *FB*. In all three cases, then, the minor axis of the ellipse lies in the same direction, on the sketch, as that isometric axis to which the plane of the circle is in reality perpendicular.

The major axis is necessarily perpendicular to the minor axis, and lies on the other diagonal of the square.

Since the cylinder is the curved surface most used in engineering, the rule may be applied to cylinders as follows: The ellipse which represents the circular base of any cylinder must be so sketched that its minor axis is in line with the axis or center line of the cylinder. Fig. 51 is an isometric sketch of a piece composed of cylinders. All the ellipses are seen to follow this rule.

In sketching cylindrical parts of objects, it is necessary to imagine them squared up by the use of isometric lines and planes. Thus the first steps in sketching the piece of Fig. 51 are shown in Fig. 52. The circumscribing of a square about a circle in the object corresponds to circumscribing a rhombus about the ellipse in the isometric sketch. It now remains to inscribe an ellipse in the rhombus. This ellipse must be tangent to the rhombus at the *middle* of each side. To sketch the ellipse, as for example the small end in Fig. 52, draw the diagonals of the rhombus to get the directions of the major and minor axes, and find the middle points of the sides (by center lines, through the intersection of the diagonals). It is now easy to sketch the ellipse, having *four* points given, the *direction* of passing through those points, and the directions of the major and minor axes.

67. Isometric Sketches from Orthographic Sketches.—A good exercise consists in making isometric sketches from orthographic sketches or drawings. The three coordinate directions, x, y and z, must be kept in mind at all times. Fig. 53, as an example, is most instructive. From the orthographic sketches, Fig. 53, the isometric sketch, Fig. 54, is to be made.

The ruled coordinate lines of Fig. 53 and the isometric lines of Fig. 54 are represented as overlapping between the figures. Most commercial isometric paper is ruled with *four* sets of lines, like this overlapping area, so that, by ignoring lines not wanted, it can be used for either purpose. When used for orthographic work vertical and horizontal lines, only, are considered. When used for isometric work the horizontal lines are ignored. Sheets of this double-purpose paper, printed in faint blue or green, are the usual "isometric paper" of commerce.

To construct Fig. 54 from Fig. 53, imagine the front view turned 45° to the left, not right, and tilted down 35°+. Choose a point for *a*. Count spaces *up to the left* (x) for points *b, f,* etc.; *up to the right* (y) for *c;* down (z) for *d.* Square out on isometric lines. The half-ellipse, *bef,* must follow isometric lines at points *b, e* and *f.*

68. Proof that the Isometric View Is Orthographic.—Isometric sketches are of course only roughly to scale. Isometric drawings are made to scale measuring always along the isometric axes. Other directions of course are not to scale.

In Fig. 55 an orthographic drawing of two views, H and V is drawn to scale. From these a projection on a U plane, perpen-

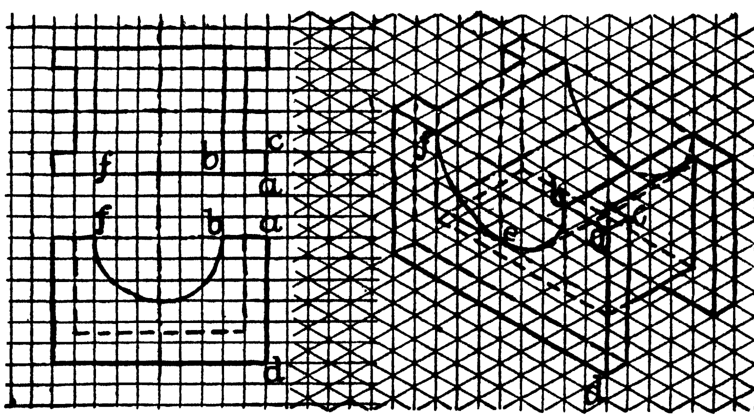


FIG. 53. FIG. 54.

dicular to V and at 45° with the plane of H, is constructed. From the views on V and U a projection upon a plane W, perpendicular to U and at an angle of 35°+ with V, has been constructed by the selfsame process by which U itself was constructed from H and V. The resulting projection on the oblique plane W is the isometric projection. It has every edge reduced or foreshortened, in the ratio of the length of $\sqrt{2}$ to $\sqrt{3}$, or to 83 per cent of its true length. An isometric thus produced from actual H, V and S views is of an awkward scale never used in practice. Isometrics are always made directly using the scale along isometric axes and are therefore in a sense oversize. Fig. 55 is of interest only as

showing that the isometric drawing is one of the orthographic family.

Note that the angles of 45° and 35°+ are the same angles used in turning the object from Fig. 40 to 41 and 42.

One can also derive the isometric projection from the orthographic by turning the object 45° in the H and V views and then tilting at 35°+ in the S view as shown in Fig. 57. This again

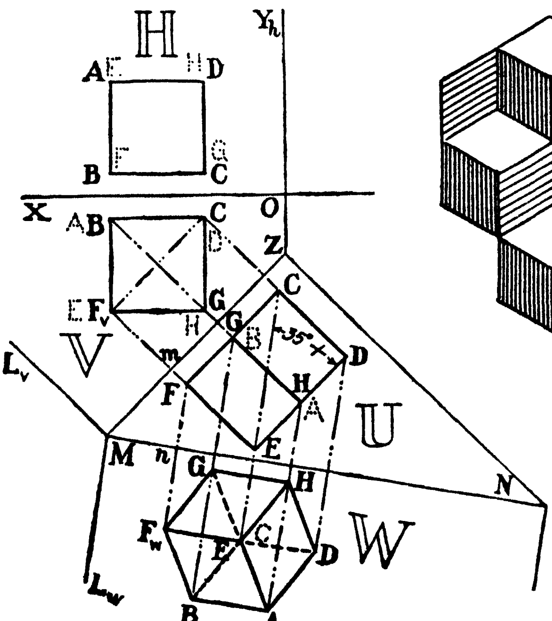


FIG. 55.

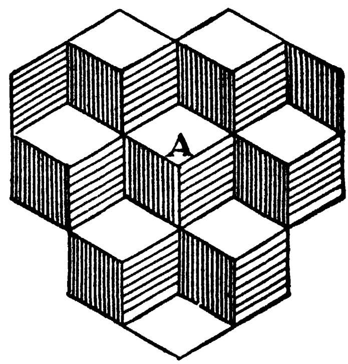


FIG. 56.

is of academic rather than practical value. Fig. 55 represents a cube and we see that we are looking upon it in the W projection along the line, *EC*, a *body diagonal* of the cube. Fig. 57 represents a brick put in isometric position by twisting 45° and tilting 35°+.

69. Requirement of Perpendicular Faces.—An isometric drawing, being a single view, cannot really give "depth," or tell exactly the relative distances of different points of the object from the eye. It absolutely requires that the object drawn shall have its most

prominent faces, at least, mutually perpendicular. The mind must be able to assume that the object represented is of this kind, or the drawing will not be "read" correctly. Even on this assumption, in some cases isometric drawing of rectangular objects may be misunderstood if some projecting angle is taken as a reentrant one. Thus in Fig. 56 we have a drawing which might be taken as the

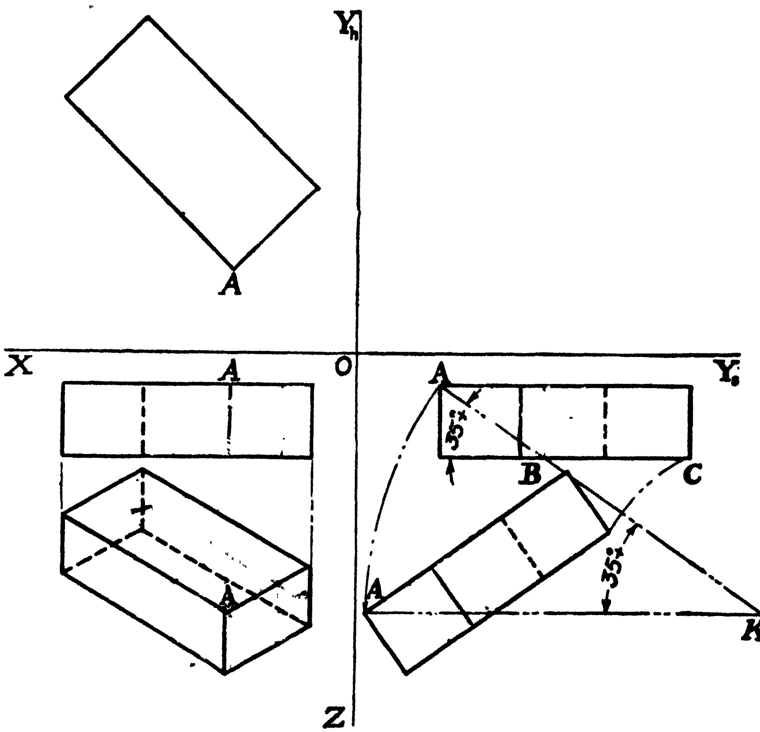


FIG. 57.

pattern of inlaid paving or other flat object. If it is taken as an isometric drawing and the various faces are *assumed* to be perpendicular to each other, it becomes the drawing of a set of cubes. Curiously enough, it can be taken to represent either 6 or 7 cubes, according as the point A is taken as a raised point or as a depressed one. In other words, it even requires one to know just *how* the

faces are perpendicular to each other to be able to take the drawing in the way intended.

This requirement of perpendicular faces limits the system of drawing to one class of objects, but for that class it is a very easy, direct, and readily understood method. Untrained mechanics can follow isometric drawings more easily than orthographic drawings.

70. The Representation of the Circle.—In executing isometric drawings, the circle, projected as an ellipse, is the one drawback to the system. To minimize the labor, an approximate ellipse must be substituted for an exact one, for *practical* purposes. In Fig. 50 the rhombus *ABCD* is the typical rhombus in which the ellipse must be inscribed. The following draftsman's ellipse, devised to be exactly tangent to the rhombus at the middle point of each side, is reasonably accurate. From *B,* one extremity of the short diagonal, *BD,* of the rhombus draw lines *Bd* and *Bc* making angles of 30° with *BD.* These cut the long diagonal of the rhombus, *AC,* at *k* and *l.* With *B* as a center and *Bd* as a radius, describe the arc *dc.* Similarly, with *D* as a center, describe the arc *ba.* With *k* and *l* as centers, and *kd* as a radius, describe the arcs *ad* and *cb.* The resulting oval has the correct major axis within one-eighth of 1 per cent, and has the correct minor axis within $3\frac{1}{2}$ per cent.

This draftsman's ellipse is exact where required, namely, on the two diameters *ac* and *db,* which are isometric axes, and it is practically exact at the extremity of the major axis.

71. Set of Isometric Sketches.—Fig. 58 is a set of isometric sketches of the details of a mechanism known as Hooke's Joint from which to make orthographic drawings. The isometric sketch is much clearer than the corresponding orthographic sketch, and the set shows clearly how the pieces are assembled.

The orthographic drawing of the *assembled* mechanism is much easier to make than the assembled isometric drawing. It is in fact clearer for the mechanic than the *assembled isometric* drawing would be, for the number of lines would in that case be quite confusing. It illustrates well the fact that isometric sketches and drawings should be limited to fairly simple objects.

Another noteworthy fact is that center lines, which should always mark symmetrical parts in orthographic drawings, should be used

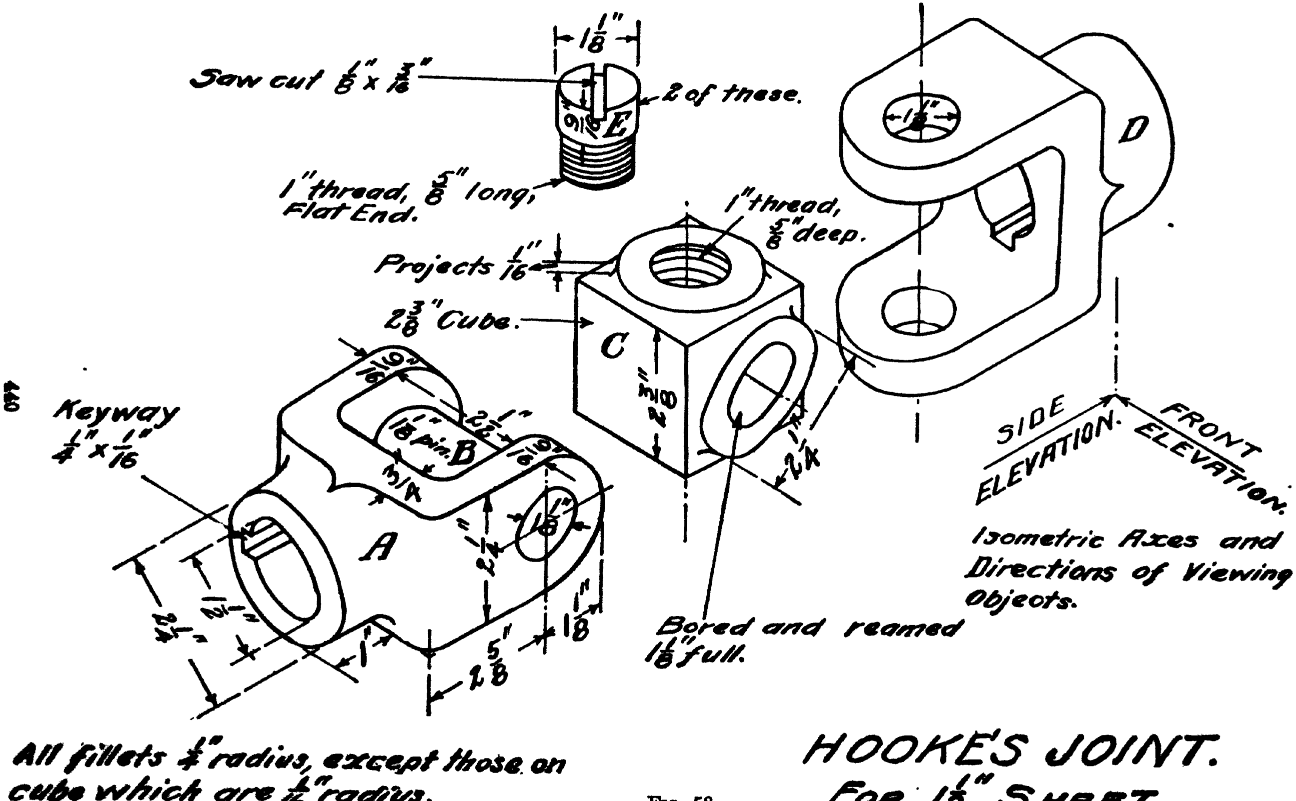

Saw cut $\frac{1}{8}$" x $\frac{3}{16}$"
$1\frac{1}{8}$"
2 of these.
E
$\frac{9}{16}$
1" thread, $\frac{5}{8}$" long, Flat End.
1" thread, $\frac{5}{8}$" deep.
Projects $\frac{1}{16}$"
$2\frac{3}{8}$" Cube.
C
$1\frac{3}{4}$"
$2\frac{1}{4}$"
D
$1\frac{1}{8}$"
SIDE ELEVATION.
FRONT ELEVATION.
Isometric Axes and Directions of Viewing Objects.
Bored and reamed $1\frac{1}{8}$" full.
Keyway $\frac{1}{4}$" x $\frac{1}{16}$"
A
B
$1\frac{1}{8}$" pin.
$2\frac{1}{2}$"
$\frac{9}{16}$"
$\frac{3}{4}$
$2\frac{1}{4}$"
$1\frac{1}{2}$"
1"
$2\frac{5}{8}$"
All fillets $\frac{1}{4}$" radius, except those on cube which are $\frac{1}{16}$" radius.
HOOKE'S JOINT.
FOR $1\frac{1}{2}$" SHAFT.

FIG. 58.

sparingly in isometric drawing. However, in Fig. 58, opposite, the piece *C* has a V.C.L. marked and piece *D* has one also for the very purpose of suggesting that *D* is to be put over *C* in such position that the two center lines become one. This justifies the center lines.

A center line on the face of one of the jaws of piece *A* is used for recording the dimensions, 1⅛″ and 2⅝″, of that piece.

Pieces *A* and *D* are alike after pin *B* has been removed from piece *A*. Consequently only *A* is completely dimensioned.

This group of isometric details is arranged in a manner to suggest assembly into one mechanism. Pieces *A, C* and *D* shut up together, the jaws sliding over the cube *C*. The pin *B*, previously drawn out of *A*, is now replaced in *A* and *C* both, their 1⅛″ bore holes being now in line. *B* is a drive fit in *A*. The bore hole of *C* is marked 1⅛″ full and thus permits easy rotation of *C* about the pin *B*.

The piece *E*, having a 1″ threaded end ⅝″ long, evidently screws into the top 1″ threaded hole of *C*, ⅝″ deep. The second piece *E* obviously screws into a similar bottom hole in *C*, which must be assumed as it is not shown.

72. Dimensions on Isometric Views.—Fig. 59 is another set of isometric drawings and is included here as an example of the way dimensions are applied. Nearly all parallel the isometric axes. Occasionally a radius or diameter does not. See the semicircular bearings on *D*. Such a non-isometric dimension does not scale properly with the others.

The dimensions, if possible, are off the pieces. This is entirely true of *A* and *B*. *C* has one that overlaps, *D* has a number.

73. Distorted Isometric Views.—There are two systems of shop drawing which may be considered as distorted isometrics. In one of these, known as the Cavalier projection, the axes of the isometric system have been forcibly twisted to other angles than 120°.

In Fig. 60 we show the same object as in Fig. 54. The *Z* axis is unchanged. The *X* axis is put at 90° to the vertical, instead of at 120°. The *Y* axis is put at 135° to the vertical (or 45°), instead of at 120° (or 60°).

Measurement along these directions are all to the same scale.

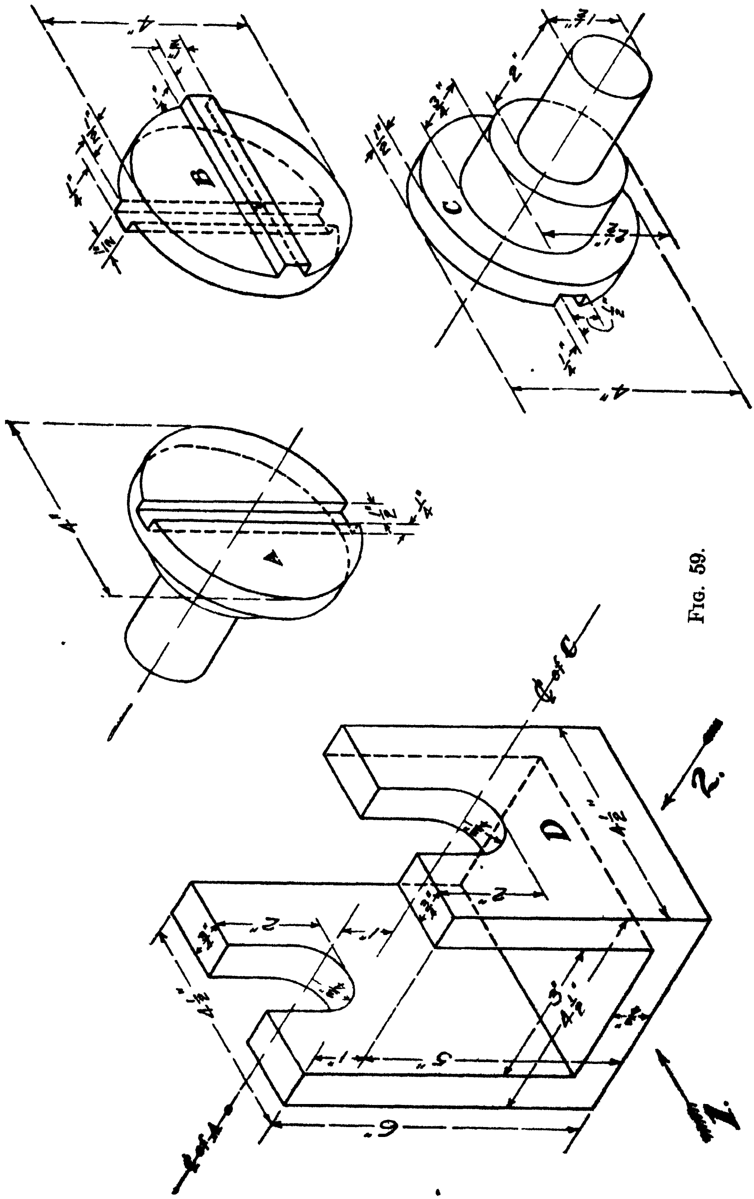


FIG. 59.

The effect is to keep a circle, in the plane of XZ, still a circle, making it easier to draw than on a true isometric. However, circles

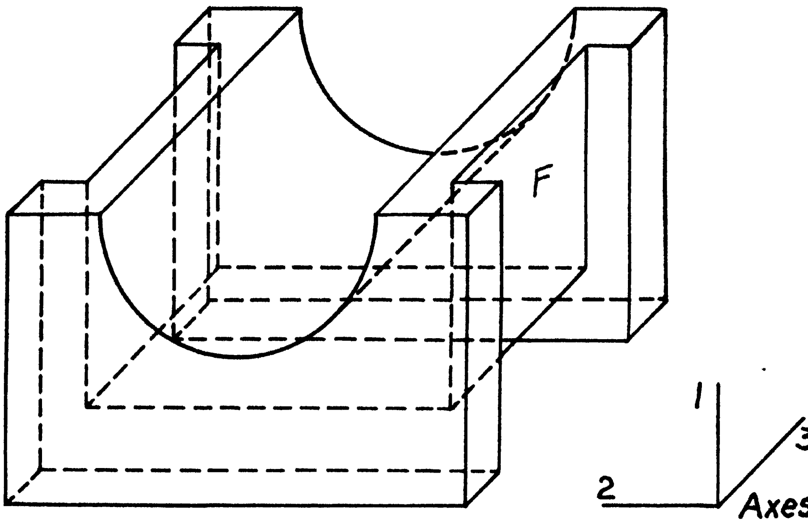


FIG. 60.

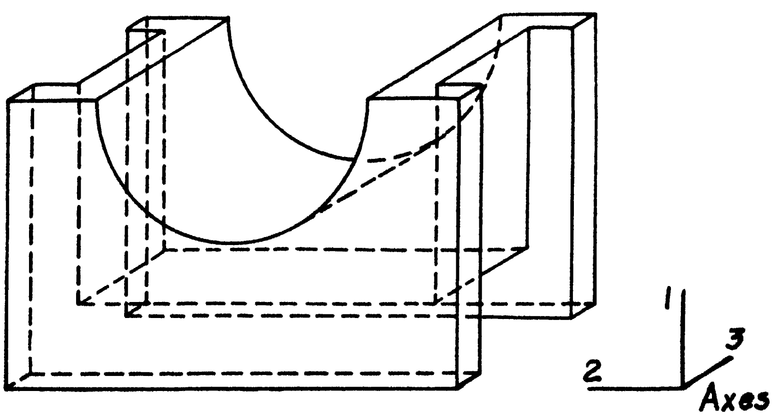


FIG. 61.

in the planes of XY and YZ would be very elongated ellipses. The method then has one advantage. It is applicable to pieces having circles and angles appearing in one set of parallel faces only.

The general effect is of violent distortion.

A second system, known as Cabinet projection, keeps the one advantage of the Cavalier projection and mitigates the unpleasing distortion by reducing the scale in the Y direction to half that in the X and Z directions. It is only partially isometric.

The method has been much used for Cabinet work to show the designs and construction of furniture. Fig. 61 is the Cabinet projection of Fig. 54. The X axis is distorted in position, the Y axis is diminished in scale.

Both Cavalier and Cabinet projections can be given a scientific derivation by resorting to systems of oblique or non-orthographic projection. An object placed square with the plane of $\mathbb{V}$, behind it, and projected upon $\mathbb{V}$ by a system of parallel projectors, making an angle of 45° with $\mathbb{V}$, and all inclining up to the NE would show on the plane in Cavalier projection.

An object so placed, but projected by parallel projectors making an angle of 26° 35′ (the tangent of which angle is $\frac{1}{2}$), and in the proper inclination of 30° up to the right would show on the plane in Cabinet projection.

These non-orthographic systems are included here because in use at times for book illustrations, etc. Usually the true isometric is much to be preferred.

Problems

(For blackboard or isometric paper.)

21. A cube of 10″ has a 6″ square hole piercing it centrally from one side to the other, and a 4″ bore-hole piercing it centrally from side to side at right angles to the larger hole. Make an isometric sketch.

22. Let Fig. 3, p. 211, represent a model cut from a 12″ cube by removing the center, leaving the thickness of the walls 3″. Let the angular point form a triangle whose base is 12″ and altitude 8″. Make an isometric sketch.

23. Make an isometric sketch of Fig. 71, p. 305, the diameter of the cylinder being 7 units and the length 14 units.

24. Make an isometric sketch of the angle piece, Fig. 62, using the spaces for 1″ distances.

25. Measure the tool-chest, Fig. 63, scale, $\frac{3}{4}'' = 1$ foot, and make a bill of material, tabulating the boards used, and recording sizes, giving dimensions in the order: width, thickness, length, thus:

Mark	Name	Size	Number
A	Top of Chest	$14'' \times 1'' \times 24''$	2

26. Make orthographic sketches of the bracket, Fig. 47. Views required are plan and front elevation. (On cross-section paper use the unit distance for the unit of the isometric paper. On blackboard let each unit of the isometric paper be represented by 2″.)

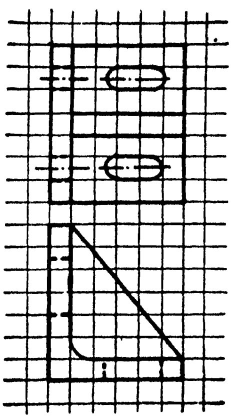


FIG. 62.

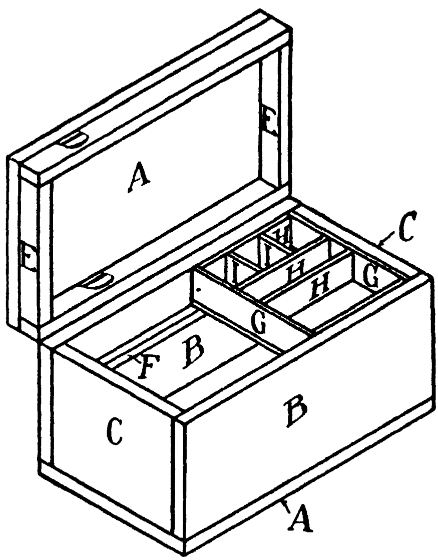


FIG. 63.

27. An ordinary brick measures $8'' \times 4'' \times 2\frac{1}{2}''$. Make the isometric drawing, the Cavalier projection and the Cabinet projection.

28. From Fig. 58 make a plan and a front view of the piece *D*.

29. From Fig. 58 make a plan and a front view of the cubical piece *C*.

30. From Fig. 59 make a front view of piece *D* (arrow No. 1) and a side view (arrow No. 2).

31. From Fig. 59 make two orthographic views of piece *B*.

CHAPTER V

PROCEDURE IN SKETCHING SMALL MACHINE PARTS

74. Progression in Sketching.—This chapter is to be read and studied in connection with the series of models served out for sketching. We aim first to produce eye sketches on coordinate paper, and later, eye sketches on unruled paper. From these sketches some will be chosen for making pencil and ink drawings in the regular manner, and some for making scale sketches ready for tracing, a method for quick results.

The first models treated will be discussed in detail, sketches shown complete, and the work of the midshipman reduced to following a set course. As each model is taken up, less and less is prescribed and more and more left to judgment. It is, of course, our aim to cultivate the judgment by this process.

For a given piece of machinery, which, for convenience, we will call our model, there are several possible sets of views which may all exactly depict the model, some in a little better style than others, but all correctly. It is in making a happy choice that good judgment shows itself.

75. Selecting Planes to Parallel the Planes of Projection.—In the use of judgment, no fixed rules can be given, or the resulting act ceases to be one of judgment. There are certain principles to be considered in connection with each model and to be applied if judged suitable. These we will call **considerations**, and will letter them in the order in **which they are examined in applying them to actual pieces of machinery.**

The two first considerations govern the way in which we decide to turn the model relative to the planes of projection, in order to make the resulting views as simple as possible. This is done, without, at the time, distinguishing between the three planes of projection.

(a) Symmetry.—Most mechanical pieces show symmetry about one, two, or three planes. When symmetry is observed, the natural way to take planes of projection is parallel and perpendicular to planes of symmetry. An object is symmetrical with respect to a plane whenever, for any point on one side of that plane, there is a corresponding point on the opposite side at the same distance, so that the line joining the two points is perpendicular to the plane and bisected by it. An object and its image in a mirror are symmetrically placed as regards the plane of the mirror. Many pieces have parts which are symmetrical while as a whole they are not symmetrical.

One of the most important things to learn in all drawing, is the habit of noting symmetry and detecting the exact plane which is the basis of the symmetry observed.

(b) Plane Faces Mutually at Right Angles.—Many pieces have many plane faces at right angles to each other. In such cases it is natural to take the planes of projection parallel to such faces.

From considerations of symmetry, and of the plane faces on the object, one can select three mutually perpendicular planes to which the planes of projection are to be parallel. This is the first step in sketching. We have not, as yet, decided which plane is to be parallel to which.

As an example, suppose that we have as model a brick, or some object of that shape. Symmetry and the plane faces of the object combine to dictate the selection of planes, but give no hint yet as to which of the six faces had best be turned up.

76. Choice of Plan.—With a general idea of the planes of projection in mind, the selection of one to act as the H plane on which to draw the "plan" is the next step.

(c) Any object which habitually is placed in one position relative to the earth, is most naturally drawn with "plan" taken as a true view from above. Thus, a mechanism operated by gravity, such as a pendulum clock, is naturally drawn in the position it must occupy. A table or stool is such an object.

(d) Any object whose general shape is like a brick, that is, one dimension quite long, one quite short, and one between the others, is most naturally placed so that the longest dimension is an x

dimension, the medium dimension a y dimension, and the shortest dimension a z dimension. The box of drawing instruments is such an object.

(e) Any object of the general shape of a disc, *i.e.*, any round flat object, is also usually placed on its flat side, so that the plan shows the circular shape to the greatest advantage. Any short cylinder is included in this class. The ink bottle is an illustration of this case.

(f) A long cylinder is generally placed horizontally with its length extending from left to right. A prism or non-circular cylinder is also generally placed so that the plan and front views are those which are largely formed of straight lines, and the side view is that which shows the curved, polygonal, or irregular contour.

(g) An object which has a large flat base, on which it is most natural to place it, may often be so placed regardless of its customary position in a machine.

These considerations are not fixed rules. They are guides to good judgment, and they may conflict one with the other, so that a choice between them must often be made.

77. Number of Views and Sections Needed.—There is no general rule except that one should take as many views as are necessary to show every detail clearly and **no more.** Until we have more knowledge on which to base our judgment, we may take three views as the standard number, except that solids of revolution may often be so placed that two suffice. See Arts. 4 to 6, pages 392 to 394.

78. Size of Sketches.—Sketches must be large enough to allow a full set of dimension lines to be applied to them, without obscuring the sketch. Only by experience can one gain judgment of this kind. In general, novices are tempted to make sketches too small. The more complicated the piece the larger the sketch required. Large simple pieces may be made small without detriment, but one must always examine the detail parts and make the sketch large enough for them.

If there is a part which is invariable, like a "parallel middle body," much of it may be broken out and the ends brought in towards each other.

This enables the parts having many details to be enlarged in size.

In dimensioning sketches follow Chapter III, Arts. 28 to 35.

In the sketching course to follow the student is free to change to isometric sketching if the subject lends itself to that treatment. In that case, dimension as in Fig. 59. If an isometric sketch is made it must be supplemented by orthographic sketches, which, however, may be made of a small size and without dimensions.

The decision as to what views and what sections are needed must be recorded by orthographic sketches before any work of drawing can begin.

79. Models for the Sketching Course.—In Figs. 64 and 65 are shown a number of models used for this course. The object is to give a general idea of the models used. Similar models are quite as available as these and may be substituted for them. Most of these models are of a black compound similar to Bakelite but were whitened before being photographed. They represent pieces originally of wood, brass, steel or porcelain and are referred to in the descriptions as of their original material. They are:

1. Armory Flooring Block.	12. Bell Chuck.
2. Guide Block.	13. Bored Molding.
3. Bottom Journal Brass.	14. Bored Molding.
4. Bored Molding.	15. Collar Nut.
5. Face Plate.	16. Eccentric Disc.
6. Cold Chisel.	17. Socket Wrench.
7. Test Piece.	18. Gland.
8. Molding.	19. Link.
9. Molding.	20. Forked End.
10. Cylinder Cover.	21. Crosshead.
11. Insulator.	22. Stuffing Box.

The order given by the numbering of the models is that assigned for use at the Academy. In the photograph they have been arranged by size and shape. It is not essential that any particular order should be rigidly observed.

It should be understood that the position of each model in the photograph is that which seems to give the best general idea of the piece, and is not at all that which gives the best drawing and permits the recording of exact information about its shape. The choice

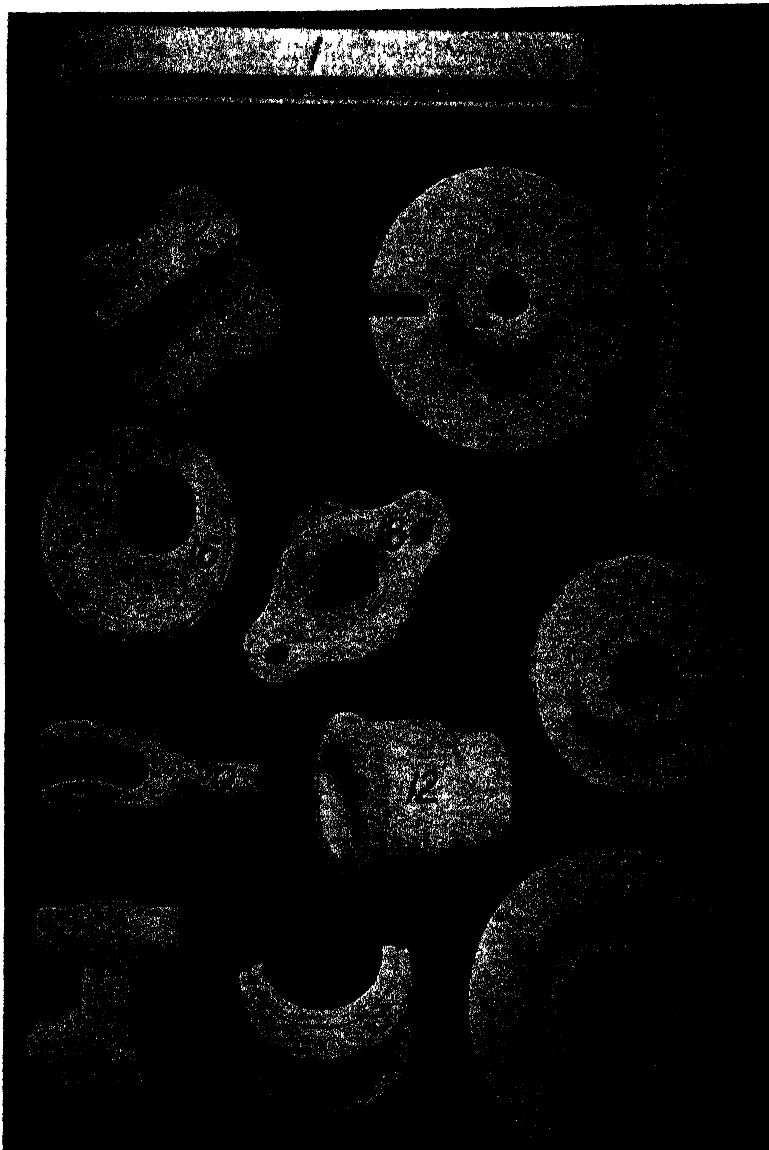


FIG. 64.

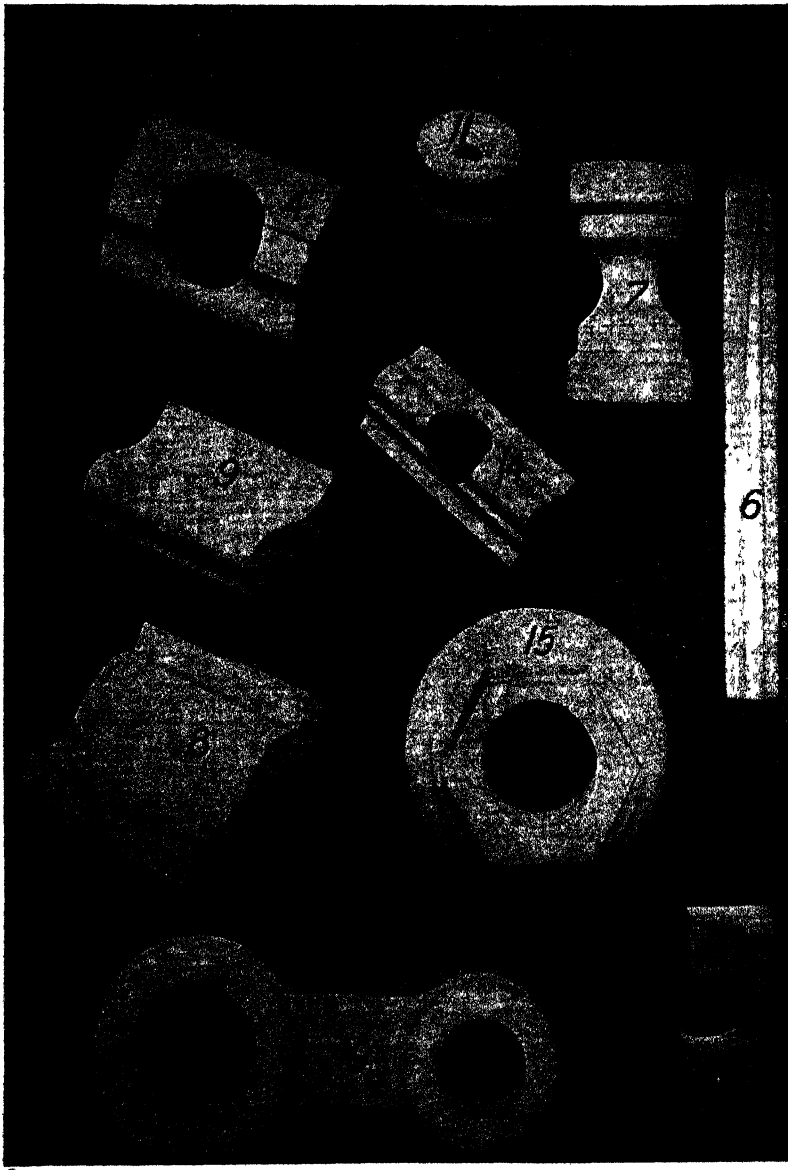


FIG. 65.

of position for viewing the model is one of the acts of judgment necessary in the process of making its sketch.

80. Armory Flooring Block.—These blocks are laid in "herring-bone fashion" over a cement floor in a binder of molten pitch. The pitch gets a grip on the dovetail groove, formed by two adjacent blocks, as may be seen when looked at from the underneath side.

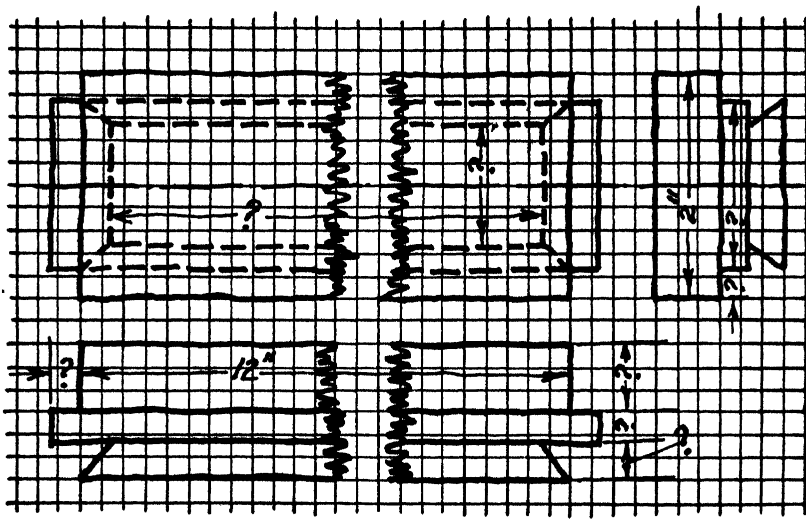


FIG. 66.

In **No. 1** of Fig. 64 the block is viewed partially from below. When several blocks are fitted together, it will be seen that the projection at the end of one hooks under the overhanging side of a block at right angles to it.

This model is to be drawn on cross-section paper by eye, and we wish to apply Arts. 75 to 78 to it, by a systematic examination. We see that the piece is intended to be absolutely symmetrical about two planes, one a longitudinal vertical plane and one a transverse plane. Consideration **a** yields this result, and we must have these two planes parallel to planes of projection.

Consideration **b** applies. All surfaces are at right angles to each other except the undercut beveled edges.

The third consideration, **c**, also applied. It is natural to draw the block with that side up which will be the "tread" when the floor is laid. This does not tell us which way to turn the block after making the tread the top horizontal plane of the model.

Consideration **d** requires us to put the length of the piece from right to left, and completely locates the model relative to the planes of projection.

We next consider the number of views. Three is indicated at once. No sections are required, as there is no complicated interior to expose.

From the shape of the piece we see that if the side view is placed to the right or left of the plan, not of the front view, the drawing will be compact. There is really no choice between right and left here. Either will do.

The size of sketch should be approximately the size of the piece, in order to show the undercut portions clearly. A large part of the parallel middle body may be cut away to advantage. We thus get the sketch shown in Fig. 66.

When this model is served out for sketching, a midshipman should close this book and open the sketch book to a page of coordinate paper or use a loose sheet. He should then reproduce this sketch and proceed to measure and record dimensions, using the folding foot rule. Little inequalities are assumed to be unintentional. For instance, if the projection at one end exceeds the other by $1/32''$, decide on a correct dimension and make both ends the same. Obviously it must not exceed the space under the edge of the adjacent block it is intended to fill.

81. Guide Block.—In Fig. 30, No. 14 represented a Guide and Slide Rod. The squared portion of the rod slides back and forth in a hollow squared opening in the guide. If it is necessary to make the guide in two pieces, one bolted to the other, in order to take the mechanism apart with ease, a piece similar to **No. 2** of Fig. 64 results. The piece requires four bolt holes, one in the center of each rounded corner. The one photographed on page 450 had no bolt holes but the black models are all properly drilled.

The considerations which apply are **a**, **b**, **d**, and **g**.

(a) There are two planes of entire symmetry.

(b) The largest plane surface and planes parallel to it are per-

pendicular to the two planes of symmetry. We thus have three planes mutually at right angles.

(d) The piece is a little longer in one direction than in the other. The third dimension is quite small, and is naturally taken

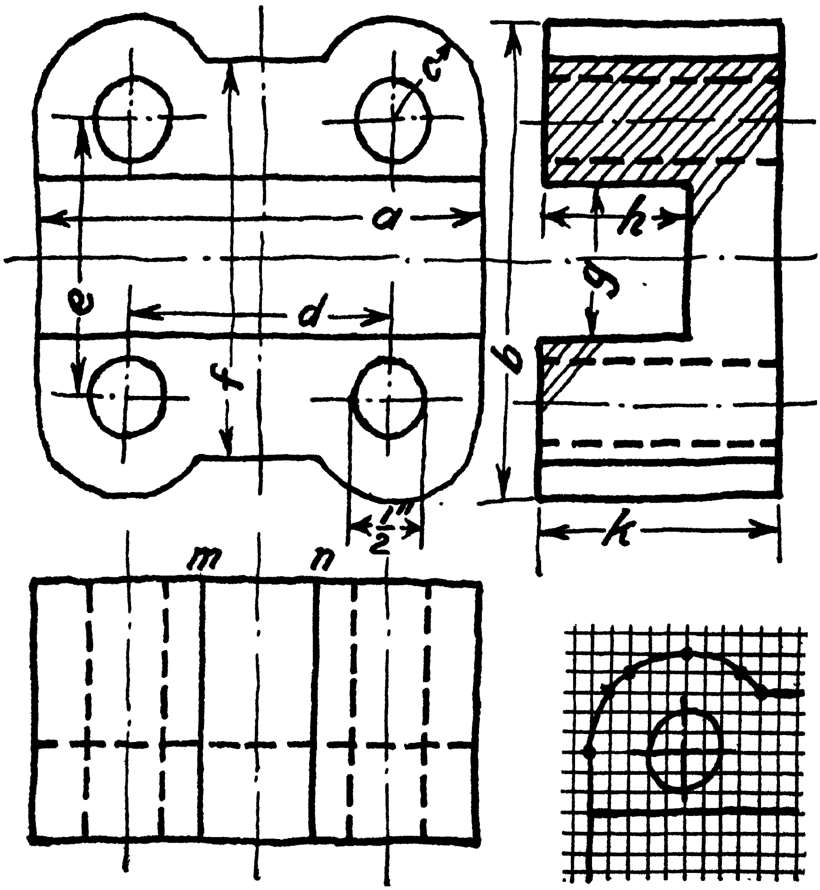


FIG. 67. FIG. 68.

as a z dimension. The dimension lengthwise of the rectangular groove is the longest and is taken as an x dimension. The width at right angles to this, which we take as a y dimension, is so nearly equal that no one would criticise if x and y were interchanged.

(g) The piece is naturally placed with its largest plane face down. In the actual engine this was taken from, the slide rod was a vertical valve stem. The position of the piece in the machine was therefore quite different from that chosen for the drawing.

Consideration c has been disregarded entirely.

Three views are sufficient. To show the amount of metal in the middle body of the piece, the side view may well be made in section. It is best placed abreast of the plan. The material of the block is supposed to be cast-iron, though the model may be of brass or of plaster for instruction purposes. The hatching of the section indicates cast-iron. See the Table of Standard Hatching on page 603.

The finished sketch will appear as in Fig. 67, with two differences. It will be on coordinate paper, and the letters will be replaced by dimension figures. Fig. 68 is a small part of the plan executed on coordinate or cross-section paper, showing application of Art. 54.

The curved surfaces of this piece are parts of cylinders whose axes are the lines of the bolt holes. This gives an equal thickness of metal around the bolts at the corners of the piece. It is rather difficult to determine the centers from the partial cylinders. Some judgment must be used, and it is natural to expect that the center to center distances of the bolt holes should work out in even eighths of inches.

In reproducing this sketch with the model at hand, but with the text-book closed, one can assume centers of cylinders at intersections of ruled lines and plot circles by assuming an easily plotted circle, like that whose radius is 5 units, as in Fig. 68.

82. Use of Calipers.—In measuring models, the calipers must often be used to get accurate results. In the case of this guide block, the edges may be rounded or imperfect, so that the dimension *b* could not be directly taken by laying a scale across the top of the block.

In such a case the outside calipers must be fitted to touch the sides of the model well below the edge. See Art. 58.

83. Bottom Journal Brass.—Journal brasses were shown in the drawing of the pedestal bearing, No. 1, of Fig. 30. The bottom journal brass is shown in perspective on Fig. 64, **No. 3**. The piece

has two planes of symmetry, and if it were matched with the top journal brass, the plane at which they would touch each other would be a third plane of symmetry. In the drawing this top plane of the bottom brass is shown by a center line as are the others. It is a center line for the pair of brasses.

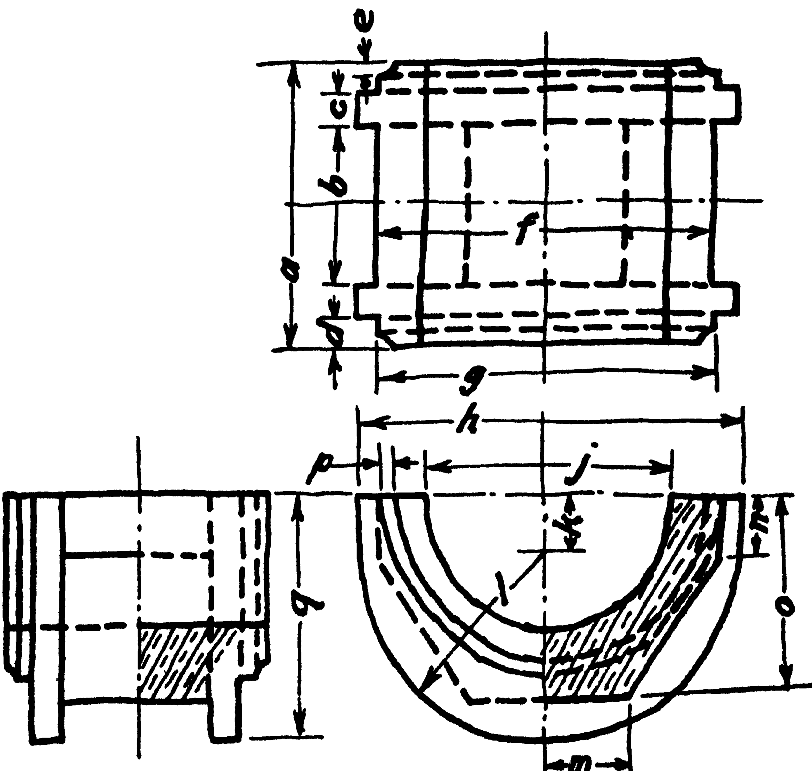


FIG. 69.

Considerations **a**, **b**, **c** apply, and to a less extent **d**. Three views are needed, and both front and side views had best be taken half in section, in order to show the thickness of metal in the center where the greatest pressure comes. The material is bronze (not brass), and the hatching is for brass, bronze or "composition." The same hatching is used for all alloys in which copper predominates.

In Fig. 69 the views shown are plan, front-view-half-in-section, and left-side-view-half-in-section. Of course quite different arrangements are equally good. The student should make his sketch larger to give more room for applying the dimension figures, here represented by letters only. The rounded projections whose radius is *l*, as seen on the front view, are the flanges. Like those in Fig. 31 they secure the brasses against endwise motion.

No dimension for the slanting face between the flanges is given. Dimension *g*, *n*, *o* and *m* determine the ends of the slant line which are enough. Dimension *k* is found indirectly. *h* and *q* are found by direct measurements. *l* is half of *h* and *k* is equal to $q-l$. The

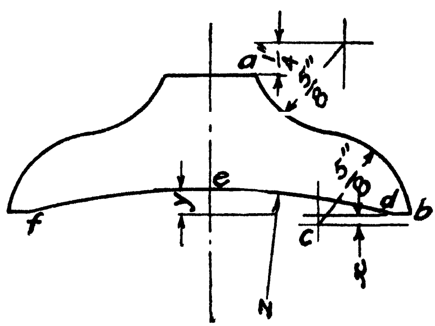


FIG. 70.

contour of the flange is a semicircle, radius *l*, plus two tangent lines, length *k*.

84. Model No. 4.—Sketch this bored molding on coordinate paper, but let it be the last to be so sketched at present. Considerations **a**, **b**, **d**, and **g** apply. The curved surfaces of this model look formidable at first, but they prove to be only cylindrical surfaces. The side or end view shows a "reversed curve," which is in reality only two arcs of a circle of radius $\frac{5}{8}''$, tangent to each other. The center of the top, or concave arc, is on a plane $\frac{1}{4}''$ above the flat top of the model. The other, or convex arc, is tangent to the first and passes through the point of extreme width of the base, *b*. When the piece is dimensioned, the $\frac{1}{4}''$ must be recorded as shown in Fig. 70, but the corresponding dimension, *x*, can only be determined on

an accurate drawing, after the center *c* has been located by trial and error methods, working from the concave arc and the point *b*. The concave depression in the base is assumed to be a cylindrical depression, and the "rise of arc," *y*, measured. On the drawing a circle is passed through the three points, *d*, *e*, and *f*, and its radius measured and recorded at *z*.

The sketch of this piece requires no section. The bore hole produces lines of intersection with the curved surfaces of the model. Choose a set of cutting planes which will give points on the intersections, and mark one on the sketch to show the method.

85. Face Plate.—This is **No. 5**, on Fig. 64. This model, and those which follow, should be sketched on unruled paper. The first

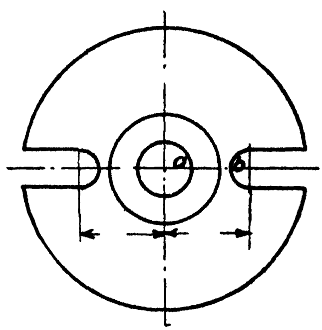


FIG. 71.

sheet in the sketch book following the coordinate paper is the natural one to use for this purpose, or a loose sheet may be issued.

We see from the photograph, and from the model itself, that this piece consists of a flat disc with a cylinder projecting from it. An axial bore hole through both disc and cylinder, two radial slots in the disc, and a filleted junction of the two parts, complete the description. The model represents a piece of forged steel. In use, it is threaded on the inside and is screwed on the spindle of a lathe. It then rotates with its own axis horizontal.

Make a sketch of this piece after testing our considerations, **a**, **b**, **e**, and **g**. **c** is disregarded in favor of **e** and **g**. One large circle may be drawn by the hand, used as a compass, in starting this

sketch. See Art. 55, near end. Do not try to show the piece threaded.

The piece is a surface of revolution, and two views suffice. Assuming the plan to have been selected by consideration **g,** the other view may be either a front view, below the plan, or a side view to the right or left. The second view may be made half-in-section to advantage, and this section should show the **section of minimum strength,** not of maximum strength. This requires the section to follow the radius on which one of the slots is cut, as *ab* in Fig. 71. The line of the slots must be made a horizontal line on the drawing, if the second view is a front view, and it must be made a vertical line, if the second view is a side view.

Whenever a section may be so taken as to show the minimum strength of metal for that part of the piece, it is a good principle to take it so. This is far better than to show some larger section giving an idea of greater strength. Go on the principle that the least strength is all that can be relied on, and is that which should be made apparent to the eye.

The hatching for forged or wrought steel is found in the table of **Standard Hatching**, p. 545. No. 2 has superseded No. 15.

In the use of the face plate, bolts may be slid into the slot for bolting on pieces of metal to be cut by the lathe tools. The center of a bolt cannot approach nearer to the center of the face plate than the center of the rounded end of the slot. This "center to center" distance should be given, rather than the distance to *b*, the extreme inboard edge of the slot. See Fig. 71.

86. Cold Chisel—No. 6, page 451. This is a tool made of "high carbon" or "tool steel," in the shape of an octagonal rod, with two sides sharpened to a wedge shape, and, at the extreme point, ground to a chisel of about 60° angle. A chisel is tempered so that the cutting edge is extremely hard, yet fairly tough, while the end which receives the hammer blows is left in a very soft, tough condition, known as annealed. The hammered end must be of such quality as to "mushroom," without danger of chips flying off at the risk of the eyesight of workmen. The term "cold" means that it cuts cold iron. A "hot" chisel is much sharper, and is used to cut red hot iron, which cuts more easily.

In this piece we have the usual amount of symmetry. Consideration **f** applies. Make two longitudinal views and an end view looking on the sharp edge.

87. Test Piece.—No. 7, of page 451. This piece is of simple shape, a succession of cylinders, cones, and one more difficult surface of revolution. The piece is of steel, iron, cast-iron, brass, or bronze, as the case may be. Any piece of metal may be cut into this form, in order to test it in a machine which grips the large ends, and pulls them apart, until the piece breaks at the neck. At the neck the contour, which generates it, is a circular arc with short tangent lines at the ends. This piece is completely symmetrical. It is on the borderland between a short cylinder and a long one. Either **e** or **f** may be taken as applying. Two views are sufficient, since it is a surface of revolution.

88. Model No. 8, Molding.—This is shown in Fig. 65. There is but one plane of symmetry. Under consideration **b**, notice that, apart from the end planes, which are parallel to the plane of symmetry, all the other plane faces are perpendicular to the plane of symmetry, and five of these are parallel or perpendicular to one another. The remaining plane is then cast out of consideration, and becomes an inclined plane on the drawing. Consideration **b** has here quite overpowered **g**. The overall dimensions of the piece are nearly the same in all directions, when the piece is held so that the largest plane face is a slanting one, as we are obliged to do for the reasons given above. It is thus a matter of indifference what view is taken as plan. There is a great tendency to make the curved edges appear on the side view under **Cons. f.** This is obtained by placing the plane of symmetry parallel to $\mathfrak{S}$. The curved edge is formed of two arcs of circles.

89. Model No. 9, Molding.—See Fig. 65, page 451. The description and the explanation given for No. 8 apply to this piece also, with almost no change. The radius of the large, convex cylindrical portion is fairly easy to obtain, while that of the concave cylindrical portion cannot be measured very exactly. Judgment has to be exercised here. If necessary, measurements by offsets are resorted to. See Art. 93.

90. Cylinder Cover.—No. 10, of Fig. 64. A steam cylinder is a

hollow cast-iron cylinder for holding steam. A piston moves within it, and there is a mechanism for letting steam in and out. This cover closes one end of the cylinder. The large, flat rim is a flange which fits a similar flange on the cylinder. Bolts, through holes drilled in the flanges, hold them together. This particular cover has never been drilled for bolts.

In spite of some irregularities, the dome-shaped center must be considered as a hollow hemisphere, and the generating line of the solid of revolution must be taken as made up entirely of arcs of circles.

The student can easily tell what considerations apply here. Two views are sufficient, but the front or side view should be half-in-section. To start the plan, one circle may be drawn by spinning the paper. It need not be so large as the model, as the model is fairly simple.

The flange is cut away at one place. Do not record the length of the cut edge, but record instead its distance from the center.

91. Insulator.—No. 11, of Fig. 65. This porcelain insulator for electric wiring is a surface of revolution. Either **e** or **f** applies. It is a piece very similar to the test piece, Art. 86, and needs no more discussion. If a section is made refer to p. 545 and use the hatching shown for glass.

92. Bell Chuck.—No. 12, of Fig. 64. This chuck is threaded, like the face plate, and is screwed on to the spindle of a wood lathe (one for cutting wood). The generating line is made up of a straight line of 1″ length, a concave arc of a circle of $3/16''$ radius, a convex arc of the same radius (tangent to the first), another straight line, another concave arc of $3/16''$ radius, and another convex arc tangent to the last-mentioned arc. The model is imperfect in places, but the contour should be treated as if exactly as described. The interior is *slightly* conical. The material of this piece is taken as brass.

93. Bored Molding, No. 13.—This model, shown on Fig. 65, is similar to half of that described in Art. 84, but with the bore hole differently placed. The curved edge seen on the end may be taken as consisting of two arcs of circles joined by a straight line, tangent to each. Make the sketch larger than the piece itself, of three views,

and show on it what cutting planes will serve to determine the line of intersection.

In dimensioning the model, locate the center of the bore hole relative to the back plane of the piece.

The curved contour, at the end, may be taken as made up of arcs of circles connected by a straight line, with little error. When it is necessary to be very exact, the curve is recorded by a method known as offsets. To illustrate that method, place the model on a piece of cross-section paper with two straight edges in coincidence with ruled lines, and trace the curved edge. If a series of measurements are given, as in Fig. 72, the contour is said to be determined by offsets. It is a method very applicable to non-circular cylinders.

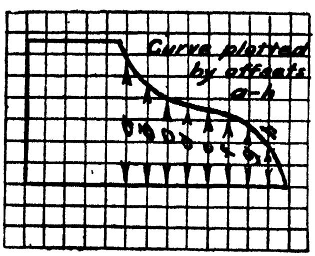


FIG. 72.

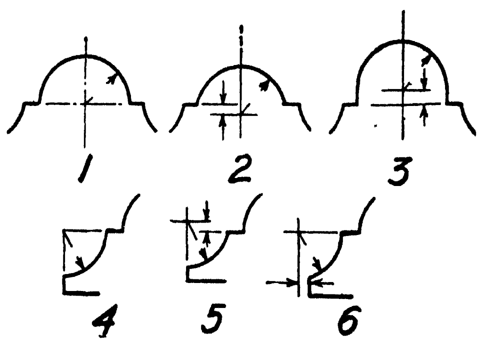


FIG. 73.

94. Bored Molding, No. 14.—This is shown in Fig. 65, p. 451. Obviously **a** and **b** apply. We have two planes of symmetry and a large, flat base perpendicular to them. **d** and **g** also apply.

The top ridge of the piece may be an exact half cylinder, or more or less than that. What it is, must be determined by careful measurement, and shown by the dimensions. Record according to one of the forms of Fig. 73, 1, 2, or 3.

In the same way, the concave grooves along the sides may be more or less than quadrants of cylinders. Record measurements as in Fig. 73, 4, 5, or 6.

The sketch should consist of three views, without sectioning any part. The bore hole through this model produces a line of inter-

section. The sketch should show a method of determining this curve. An auxiliary cutting plane should be shown by a construction line and marked as a cutting plane. From it, projecting construction lines should show the work for finding a point on the curve of the intersection, in that view in which the curve appears in a non-circular form. See Fig. 77, later, for a similar case.

95. Collar Nut.—No. 15, of Fig. 65. Nuts and bolts are used in any position, so consideration **c** does not apply. **e** and **g** apply. Do not attempt to make any section, or to sketch the screw thread, in any realistic way. In the plan it appears, conventionally, as two circles, one of $1\frac{3}{4}''$ diameter, broken, and one of $1''.53$ full. This nut is for a $1\frac{3}{4}''$ bolt, and the circles represent the "major" and "minor" diameters of the screw thread as will be explained later. For *large* threads the front and side views are conventionally drawn with four parallel broken lines projected from the circles. This is illustrated well on page 546, Figs. 3 and 5, showing plan and front view of a standard square nut. It is a matter of judgment when, in representing *small* threads, these four lines are reduced to two only (major diameter) or none at all.

Three views had better be drawn. In the plan, place the long diameter of the hexagon, a line from corner to corner, horizontal. A hexagon is best drawn by circumscribing it about a circle, not by inscribing it in one. The size of hexagon on this collar nut is not the standard size for a $1\frac{3}{4}''$ nut but is special and must be measured.

The collar portion has a contour chiefly formed of two arcs of circles. The concave arc has a radius of $\frac{3}{16}''$. The convex one a radius of $\frac{3}{4}''$, and its center is on the plane of the flat base of the piece.

The collar is of a shape known as the "Ogee." Washers of this form are quite common for use with ordinary nuts. The collar nut is the combination in one piece of the two. The ogee washer or collar increases the surface on which pressure, due to screwing up the nut, is felt. Castiron ogee washers are much used on bolts which fasten timbers together. Spreading the pressure preserves the wood from being crushed.

96. Eccentric Disc.—No. 16, of page 450. The material of this disc is supposed to be cast steel. The important dimension is the eccentricity, or center to center dimension. This should come out

in even eighths of an inch, from calculations from measurements which can be taken directly. Draw as a disc, with the crescent-shaped cavity up. Place the line joining center of eccentric to center of bore hole in a vertical line on the plan. It would be equally correct to place it horizontally, but if so, the following description will not exactly apply.

Three views are required, plan, front elevation, and section-on-side-elevation. This will show the section of minimum strength, where the bore hole comes nearest to the edge.

The crescent-shaped cavity is supposed to have vertical walls filleted at the bottom with a fillet of $3/16''$ radius. The outside edge of the crescent is supposed to be a circle concentric with the center of the eccentric, and the inside edge one concentric with the bore hole. At the ends, round off with a circle of a radius that will bring the horns of the crescent just to the center line of the eccentric. This is found by trial. This whole cavity is a device to make the casting lighter. It is located where there is more metal than is required for strength.

97. Socket Wrench.—No. 17, of p. 450. This piece is a long rod having cylindrical, conical, and prismatic sections. It is treated as a long cylinder, and end views placed at each end. The socket at each end is a hexagonal cavity to fit over a nut or bolt head, and the end views are to show these clearly. The square prism is to permit a monkey wrench to turn the socket wrench, which in turn will turn the nut. It is used in places where the monkey wrench cannot get at the nut directly, due to obstructions.

The end views are partial views only. Each one extends only to the prismatic section and shows no dotted work for any part beyond.

A small part of the longitudinal view may be sectioned to show the thickness of metal around the hexagonal socket or cavity. The material is wrought steel.

98. Gland.—This is **No. 18,** of Fig. 64. The piece consists of two parts, the gland proper and the flange. Its function is explained in connection with the stuffing box, in Art. 102.

The flange is not a circular one, but since it is intended for two bolts only, it is reduced to two lugs or projections. The entire outline is made up of arcs of circles, and the concave arcs have the

same radius as the central portion. It is a very common thing for draftsmen, in designing, when arranging a reversal of curvature, to keep the radius that was used first, for the radius of the part tangent to it.

The gland of this particular stuffing box, which is of rather unusual shape, is conical, and has a bore hole and a "counterbore." The latter is an enlarged bore hole, concentric with the first, and it ends in a 120° cone. This gland is for a special service and has an unusual shape. The ordinary gland has a cylindrical, not a conical, body, and has a plain bore hole through it.

Considerations **a**, **b**, and **d** apply. One might also place the object with the counterbore down, on the ground that **g** would then apply, but to do so seems not so natural as to stand the piece on the smaller end.

Three views are required, one of these a section or a half-section on some view other than the plan. It is immaterial whether the side view is to the left or to the right of the plan, or of the front view. The gland is of bronze, generally.

99. Link.—No. 19, of Fig. 65. This piece is of forged steel. Its function in machinery is to keep two points, the center of two pins or journals of some kind, at a fixed distance apart, but to let one revolve or oscillate about the other, and either one to turn as it will relative to the link.

The center to center distance is then the whole reason for being of the piece, and must be measured and recorded conspicuously. It should probably come out some even inch or half inch, not a sixteenth or thirty-second.

The piece has three parts, a middle body and two "eyes." Each eye has its own set of center lines. The center to center distance is the average of the distances from outside edge to outside edge of the eyes, and from inside edge to inside edge of the eyes. It is also the average of distances from outside to outside and inside to inside of the bore holes of the eyes.

Considerations **a**, **b**, **d**, and **g** apply. The side view should be to left or right of the plan, not of the front view. The front view should be made half-in-section, but since there is no center line crossing the middle body for the section to terminate on, it should

end on a break, drawn freehand across the middle body as in Fig. 74. It is of no consequence whether the large eye is to left or to right of the small one.

The sides of the flat, middle section are filleted to the outer cylindrical surfaces of the eyes by a radius of $\frac{5}{8}''$. The flat top of the middle section is filleted by a fillet of $\frac{1}{4}''$ radius. These fillet surfaces have a line of intersection. Since the case is the intersection of a surface of revolution and a cylinder, whose axes are parallel, it comes under Art. 72, p. 290, Part II, Engineering Descriptive Geometry. The line, as it appears on front and side elevations, may be quickly determined by two planes parallel to the top plane of the middle section, at $\frac{1}{8}''$ and $\frac{1}{4}''$ above it.

FIG. 74.

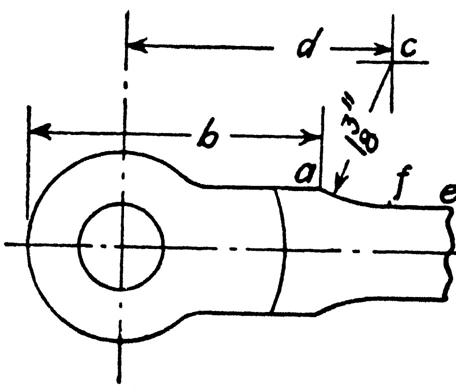


FIG. 75.

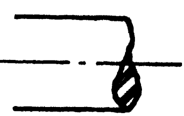


FIG. 76.

100. Forked End.—No. 20, of page 450. The material should be wrought steel, since this model represents the forked end of a connecting rod for a small steam engine. Among the considerations which apply is **f.** The piece is part of a long cylinder. It requires three views to show the piece properly, and that longitudinal view which shows the eyes of the fork in circular form is the best one to take as the plan. The broken end may extend to right or left at will.

The arc which generates the bell-shaped surface has a radius of $1\frac{3}{8}''$. On the sketch, any dimension which can be directly measured,

to locate *a* of Fig. 75, is good. Dimension *b* can be measured with some manipulation. Locate *f*, the end of the cylinder and beginning of the bell-shape, by observing the light reflections. *f* cannot be measured very accurately but enough so for our purpose. From *a* and *f* strike arcs of $1\frac{3}{8}''$ radius to locate *c*. The dimension *d* is scaled on the drawing and replaces *b*, or any other temporary one.

Give no dimension to the broken end of the rod, *e*. Make the line here a break. If the side view is taken at the broken end, the circle for the rod itself will be hatched. In that case make the breaks in the plan and front view in the form shown in Fig. 75, which requires no hatching. If the end view is at the opposite end, make the break as in Fig. 76, in order to provide a small place to indicate the material by hatching.

The lines of intersection of the plane sides with the bell-shaped surfaces are problems similar to that of page 372, and are solved by the use of planes perpendicular to the axis of the solid of rotation.

101. Crosshead Block.—No. 21, of page 450. This piece is virtually a sliding block. It gets its name from being attached to a piston rod at the end which projects from the cylinder and forming a *head* to it, and from having a journal or bearing whose axis is at right angles to or *across* the line of the piston rod. To this journal is attached the connecting rod of the engine.

In this particular form the cubical portion is the head. A hole needs to be bored in it, and the piston rod stuck through and secured by a nut on a thread at its end. The two end journals, which project from the head, have their common axis perpendicular to the line of the piston rod, and together form the "crosshead pin," to which the forked end of the connecting rod is "articulated." Like most journals, they are filleted where they join the body of the crosshead. This fillet is of about $\frac{1}{8}''$ radius, and is of importance and must not be overlooked.

Conditions are such in the steam engine that the crosshead needs a guide to slide on, on one side only. The broad, flat base is the sliding surface which rubs against the guide.

The material of which the actual piece of the machine is made is cast steel. In a large engine it would need to be of forged steel.

Considerations **a**, **f**, and **g** apply. The piece shows symmetry about three planes mutually at right angles, and intersecting at the center of the head, A. The drawing will be similar to Fig. 77. The piece is completely symmetrical with respect to a plane parallel to 𝕍. It is symmetrical with respect to a plane parallel to 𝕊, in

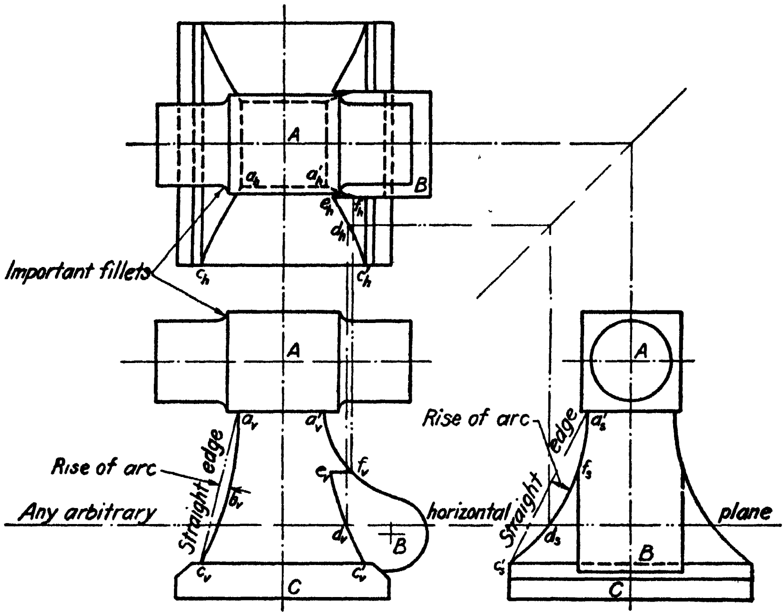


FIG. 77.

everything except the lug, B, on one side only. The head, A, is symmetrical with respect to a plane parallel to ℍ.

The concave pyramidal shape, which connects the head, A, with the sliding base or "shoe," C, must be strong. Assume that its surfaces are parts of cylinders and that its sides appear as circular arcs on 𝕍 and 𝕊. The radii of these cannot be measured directly. For temporary dimensions for the sketch, we determine the departure from a straight pyramid by measuring the **"rise of arc."** This means, for example, that we lay a straightedge from c_v to a_v, and measure the distance to the curve at the point of greatest departure, b_v. When we come to the drawing, we plot a_v,

c_v and b_v, and then proceed to pass a circle through the three points by the method of Art. 121, Chap. VII, of Part I. The curve $a'_ve'_vc'_v$ corresponds to $a_vb_vc_v$, but a portion is omitted if the lug is wide. In that case a line c_vf_v is created.

The lug is drawn first on the front view, where its profile appears. It is formed of two arcs of circles. One, almost a semicircle, can be measured with considerable accuracy and its center located. The other radius is not easily measured, but a variation in it is of slight consequence. It is just over 1″ in size. The width of the lug is shown on plan and side view. The lug is for attaching another piece.

In making the sketch of this piece, convert the front and side views, each, into a half-section, not a complete section.

The curvature of the edges, a_hc_h. $a'_hc'_h$, and a'_hf_h, on the plan, must be worked out from the other views by passing planes parallel to $\mathbb{H}$. The complete recording of this method is shown in Fig. 77. The plane marked "any arbitrary plane" gives the point d_h and a corresponding one on a_hc_h also.

102. Stuffing Box.—No. 22, of Fig. 64. A steam cylinder is closed at one end by a solid cylinder cover, bolted on, and at the other, by a cylinder cover, cast in one piece with the cylinder, or bolted on, having a hole to permit the piston rod to pass through. The rod passing through this hole and wearing it by its motion is bound to cause a leakage of steam, unless a packing material is provided to prevent this. The stuffing box is the cavity for this material. It is essentially a counterbore on the outside of the cylinder cover. The model treated here is a portion cut from the bottom cylinder cover of a marine engine. The stuffing box is the large bore hole which does not go entirely through the piece. The small bore hole, which does go through, is of the size of the piston rod. Imagine such a rod sticking through the cover. In the annular space left around the rod by the stuffing box, packing of hemp, asbestos, etc., is placed. A gland, like No. 18, of Fig. 64, but smaller, and with cylindrical body, not conical, is placed over the piston rod, and by means of bolts forced so that its body enters the stuffing box and compresses the packing. The bolts are secured to piece 22 at the two projections to the sides of the stuffing box.

They project through the bolt holes in the flanges of the gland, and, by tightening the nuts on them, such pressure can be brought on the packing that steam tightness results.

The material of this model is supposed to be castiron. Considerations **a**, **b**, **c**, **e**, and **g** all apply. Three views are needed. Plan, front view, and side view in section. The side view had best be opposite the plan.

A problem of a line of intersection modified by a fillet appears where the outside surface of the stuffing box (a non-circular cylinder) is filleted by a radius of $3/16''$ to the hollow cone. The cross-section of the non-circular cylinder is a draftsman's ellipse, whose end arcs have a radius of $\frac{3}{8}''$ and side arcs about $1\frac{3}{4}''$. The centers of the end arcs are the positions at which the gland stud bolts should be inserted, if the piece were to be actually used, and their distance apart should be recorded on sketch and drawing. The solution is explained in Art. 117 of Part II, on Engineering Descriptive Geometry, and is shown in the right half of the front elevation in Fig. 115. The curve appears also on the side elevation. Enough points for practical purposes will be obtained by passing two planes parallel to $\mathbb{H}$, at $15/16''$ and $1\frac{1}{16}''$ above the flat base of the model.

Problems

32. What are the considerations in showing the placing of a model in relation to the planes of projection? Why are they not called laws? Describe each briefly.

33. What is meant by a break to shorten a piece? Sketch one. Show by sketch the offset method of dimensioning a curve. When is the rise of arc method used? Should the dimensions so used appear in the finished drawing?

CHAPTER VI

STANDARD FASTENINGS

103. Classes of Fastenings.—Fastenings are those devices which secure together parts of machinery, temporarily or permanently, and absolutely prevent relative motion between them while secured. The semi-permanent fastenings are chiefly the devices known as bolts. The truly permanent ones, which can only be released by destroying the fastening device, are known as rivets. Certain other devices, operated by levers, cams, etc., are known as clamps. They are of many forms, and are very interesting as mechanisms, but are not so universally used as are bolts and rivets. This chapter, and the drawing sheet based on it, will treat of the forms of bolts and rivets only.

104. Why Bolts are Standardized.—There are many forms or kinds of bolts, and the engineer must become familiar with all the common shapes and names. He must know the standard sizes agreed upon by the engineering societies, in order to abide by the established standards in designing new work, when no good reason for departure from them exists. If he demands special forms, the cost of manufacture, the cost of repairs, and the delay due to repairs, will increase enormously.

The use of standards has made it possible to describe, in a few words, a bolt of any familiar type. Without reliance on the standard dimensions for the parts briefly referred to, long descriptions would be needed. It is chiefly the heads, nuts, and threads of bolts which are standardized. The length of the body must be adjusted for the service required, as, also, must be the threaded length. Thus, a bolt is described by giving its "nominal diameter" (the diameter of the body, and especially of the tops of the screw threads), the type of head and nut used, the "length under the

head," and the "threaded length." Other dimensions will then be assumed to follow the established standards, unless explicit information to the contrary is given.

Not only must the engineer know the usual forms, and the means of getting the standard sizes of these forms, but he must know, also, the standard conventionalized ways of drawing them.

First, we will treat the kinds of bolts and nuts represented in Fig. 78. We will then take up the process of finding the standard dimensions for any given size, by means of "tables of standards," and we will finally discuss the standard methods of representing them.

105. Through Bolt, B.—The common forms of bolts are shown in Fig. 78. The common form of through bolt, **B**, is a long, cylindrical rod, having an enlarged head at one end, forged in one with the rod, and, at the other end, a screw thread formed by cutting helical grooves in the metal. A nut, **A**, generally quite similar to the head in outside form, having a bore hole on the inside of which threads are cut, the exact opposite of the threads on the bolt, is used with it. The extreme end of the bolt is generally beveled to make it easy to start the nut on. The end is often called the "point."

The nut when put on the thread, and rotated in a right-hand or clockwise direction, will move along the bolt approaching the head. If the bolt is passed through two pieces of metal, each having a bore hole at least as large as the body of the bolt, the nut may be screwed until it pinches the pieces together with great force. The body of the bolt will be in tension, the head will press on one plate, the threads will press against those of the nut, and the nut, in turn, press against the second plate. If the pitch of the screw is small, friction will be sufficient to hold everything secure, except in cases of great vibration and motion.

The bolt is named a through bolt when it passes through the two pieces it secures.

A through bolt may exactly fit the hole it is put in. Such a one is a **body bound bolt**. In important places, as on moving parts, where the best workmanship is required, body bound bolts are commonly needed. The bolts which secure the brasses of a connecting rod of the marine or gas engine type are examples. On the other

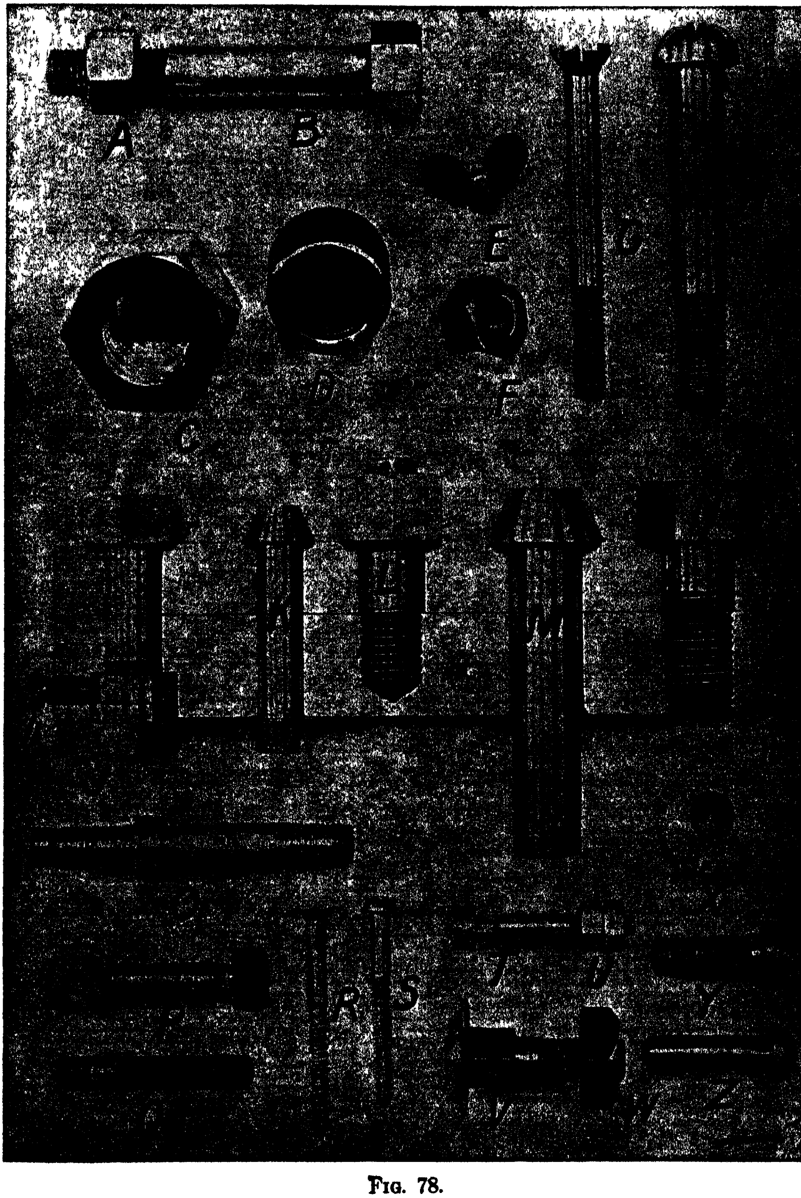


FIG. 78.

hand, when many bolts are used in a group, it is quite usual to have them a loose fit in their holes. A "clearance" of $\frac{1}{16}''$ is common.

106. Tap Bolt.—**N** in Fig. 78. This bolt is of the same form as a through bolt, but has no nut. Instead, one of the pieces to be secured by it must be virtually a nut for it. It must have a hole bored somewhat smaller than the size of body (to the diameter at the bottom of the threads, or "effective diameter"), and must then have a screw thread cut in the walls of the bore hole to fit that on the bolt.

The instrument used to cut this internal screw thread* is a form of screw converted into a cutting tool, called a "tap." It is from its need of a **tapped hole** that the bolt gets its name.

107. Stud Bolt.—**L** in Fig. 78. This form of bolt has no head. Instead, it has two points. Generally, there is an unthreaded part in the center, called the body, and two threaded ends. In use, it is screwed tightly into a tapped hole in one of the pieces it is to secure, so tightly that it becomes practically part of that piece. For this very tight joint, special wrenches, or "stud drivers," are required. A nut is used in the usual way on the free end. The intention is to be able to take the nut off and put it on again, as many times as one pleases, without loosening the fixed end. This particular stud has its free end "turned down" (removing threads) and drilled for a split pin.

Some stud bolts have square bodies. This makes it very easy to screw the stud into the stud hole by the use of an ordinary wrench, and, if the hole in the second piece of metal is a square one, it prevents the stud from unscrewing accidentally at the wrong thread, when taking off the nut, or when subjected to much vibration.

Another stud bolt is shown at **Q**. The short end is that which screws permanently into place, and the long screw at the other end is provided when a large range of adjustment is needed, as in the case of stuffing box stud bolts. Such bolts are used to force the gland into the stuffing box to compress the packing.

108. Collar Bolt.—**O** in Fig. 78. A form of double-ended bolt, with an enlarged collar in the middle, is useful when three pieces are secured together, and when it may be desirable to remove one piece while leaving the other two secured. In this case the middle of the three pieces must have a recess to receive the collar. For

example, in Fig. 79, the three pieces represent three flanges, each on a separate part of a navy feed-water heater.

The joint between *a* and *b* must be steam tight, and a sheet of flat packing material, called a gasket, is squeezed between them. So, also, the joint between *b* and *c*. When it is necessary to "break the joint" between *a* and *b*, for repairs, it is desirable that that between *b* and *c* should not be disturbed, and *vice versa.* In such a case most of the bolts used are through bolts, like No. 1 in Fig. 79; but every fourth or fifth one is a collar bolt, placed with collar below, as in No. 2. An equal number are collar bolts, like No. 3, placed with collar above. Recesses in the middle flange are prepared to fit the collars. To break the top joint, remove all the

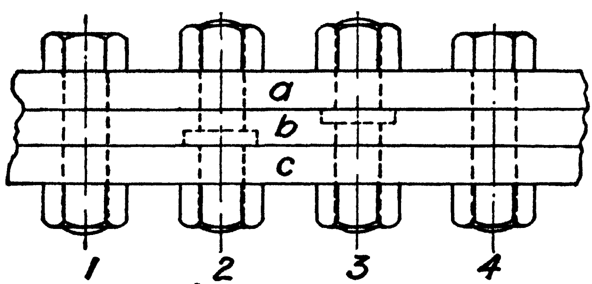


FIG. 79.

through bolts, and the top nuts of all the collar bolts. Those like No. 3, will hold the bottom joint secure. To break the lower joint, remove all the through bolts, and the bottom nuts of all the collar bolts. Those like No. 2, will hold the top joint secure.

109. Heads of Bolts.—One of the commonest forms is the **hexagonal head.** The corners, which in use will project, are beveled off or chamfered to the shape of a cone whose half-angle at the vertex is 60°. This is seen at **B**, Fig. 78.

Another common form is the **square head,** which also is chamfered.

A third form is the **round head,** shown at **T.** When screwing up a nut, it is necessary to prevent the bolt itself from turning. This is done, in the case of a bolt with hexagonal or square head, by holding the head with one wrench while turning the nut with

another. In the case of one with a round head, a lug, or projection called a "dowel," is formed on the bolt, just where the body joins the head. A little pocket, or "recess," must be cut in the metal of the piece on which the head presses, to receive the lug or dowel. The tendency of the bolt to turn, when the nut is tightened, is prevented by the dowel pressing against the side of the recess.

The T-headed bolt has as its head a short rectangular cross bar.

At **P** is shown a bolt with an eye in place of a head. This is an **eye bolt,** and it is used when convenient to swing the bolt out of the way when unfastened, but not to let it get loose entirely. An eye bolt, without a nut, is often screwed into a tapped hole prepared for it, in order to be able to lift a heavy part of a machine by suitable tackle.

110. Forms of Nuts.—The **hexagonal nut** is shown at **A** and **C**, and again at **L.** In the case of large nuts, like **C**, both sides are generally chamfered. The **square nut** is shown at **W.** Often two nuts are used, one following the other, as at **U.** In this case, they are called **nut and jam nut.** They make assurance doubly sure. The jam nut may be a shallow one. In that case, it should go on the bolt first, and press on the metal, the larger nut following it and pressing hard upon it. The shallow nut is sometimes made larger in diameter than the standard nut. It makes it easier to hold with a wrench, while screwing the standard nut against it.

A **castellated nut** or **castle nut** has a top cylindrical lip slotted for a split pin. See p. 547.

Another special nut is the **round nut, X,** with grooves down its sides, also called a **spanner nut.** It is turned by a special wrench, or "spanner."

A **wing nut, E,** is one with large wings or ears, so that the fingers are sufficient to turn it. Naturally, only small nuts are so formed.

A **thumb nut, D,** is a cylindrical one, the outside of which is roughened by small corrugations, so that the fingers may turn it. It also is used only when the pressure to be created is not great.

A **collar nut** was shown on Fig. 65, No. 15. Part of it is of hexagonal form (with or without chamfering), and part a collar, or flat disc, to widen the surface of the nut which presses on the

piece secured. It is particularly useful for bearing against soft material, like wood. Often a washer is used for the same purpose. A collar nut is virtually a nut and a washer made in one piece.

A **cap nut** is one in which the threaded hole does not extend entirely through the nut. One is shown in Fig. 97, p. 494. It is used when there is danger of a liquid leaking through, as screw threads are never a perfect fit.

111. Lock Nut and Set Screw.—There are a number of special devices for additional safety against slacking back unintentionally. They are called *lock nuts.* A standard form (but not the only standard form) is shown at **J**, Fig. 78. In this form the nut has only a small hexagonal portion, most of it being cylindrical, and the cylindrical part being of two sizes, one a very little smaller than the other. The piece of metal which receives this nut must have a cavity, a "recess" or "counterbore," prepared for it. It is of the same diameter as the larger of the two cylindrical parts.

There must also be provided a **set screw, I,** and a threaded hole drilled in from the side and tapped for the set screw. A set screw is a small screw which may be screwed in until its point presses with force against some object, to lock that object in place. The set screw in this case presses against the lock nut and prevents it from unscrewing too easily.

The points of set screws are made either conical, to press at the very center only, absolutely flat, or cupped, to press on the edges only.

112. Forms of Threads.—The usual form of screw thread for fastenings is the V-thread, flattened at the top one-eighth of its depth, and filled in at the bottom one-eighth also. The sharp V-thread is shown in Fig. 70-A, p. 299, of Part II. The flattened V-thread has twice as many helical edges. The square thread, Fig. 70-B, of Part II, and the acme thread, or worm thread, page 302, are used chiefly for purposes where much friction is not desired. The V form has great friction, and in fastenings the friction is relied on to hold the nuts from slackening back under the action of the stress they are feeling. Thus, the V form is almost the only form used for fastenings, and it is little used for transmitting motion.

113. Carriage Bolt.—**V** of Fig. 78, p. 473. This bolt is used for securing iron work to wood work. The head is a thin segment of a sphere. There is a square neck, then a round body, and a threaded length. The nut is usually a standard square nut.

In attaching it, a hole of the correct nominal diameter is bored through the wood work, and, just where the flat head is to seat itself, the hole is cut out into a square form by a chisel. The iron work goes on over the point of the bolt and then, of course, the nut. The square neck prevents the bolt from turning in the wood work, when the nut is "set up."

114. Machine Screws and Stove Bolts.—Bolts less than $\frac{1}{4}''$ in diameter are usually called screws, and those with heads slotted for the use of a screw driver are called *machine screws* and *stove bolts.*

There are several types of heads. Some are conical, and require a conical cavity in the bore hole to receive them. The conical cavity is a "countersink," and the heads are **countersunk heads.** Some countersunk heads are perfectly flat across the top, so that there is no projection whatever above the top surface of the metal, when in place. The head of **R** is of this kind, called a *flat head.* Others have a slight cylindrical extension, known as *raised countersunk heads.* See **G** of p. 473. If the raised portion is rounded it is called an *oval head.* See the figure over the column headed **G** of p. 549.

At **H**, p. 473, is shown the *round head,* almost a hemisphere, with screw driver slot.

At **Y** is shown the *oval fillister* head. Flattened at the top it would be called a *flat fillister.* See the figures over the columns **K** and **M**, p. 549.

115. Wood Screws.—The heads of wood screws are *round,* as at **S**, p. 473, *oval,* or *flat,* as at **R**. The threads are not like those of machine screws but are narrow, sharp ridges, quite far apart, running down to a sharp "gimlet" point. See the NE corner of p. 549. These threads cut their way into wood, but leave the wood between threads strong enough to hold well. A large wood screw with a square head is called a *lag screw.*

116. Ordnance Screws.—In building guns large screws, with standard NF threads, but with heads like machine screws are used. See p. 550. The heads there shown are the *oval, raised countersunk, flat, fillister,* and *round.* See **G** and **H** of Fig. 78, p. 473.

117. Rivets.—These are *permanent fastenings.* Two pieces to be riveted together are drilled with holes of the proper size. A rivet has a head but no threads. When in its hole the *point* projects through the pieces as shown at **M**. The point is now formed into a second head by great pressure applied by a riveting machine. Small rivets, less than $\frac{1}{2}''$ in size, are "closed" when cold. The steel used is very tough and pliant. Larger rivets are heated red hot to soften them when driven. The new formed head is still called the point, to distinguish it from the original head, which usually has exactly the same shape.

M, on page 473, shows a rivet with "pan" head, ready to be "driven" or "closed." **K** shows one already closed. The rivet before driving is a loose fit in its hole. The driving swells it, all along its length, until it exactly fills its hole, if the riveting is good.

Other forms of rivet heads and points are in common use. The round head, **Z**, is very common. See page 161. The countersunk and raised countersunk heads are used to give smoother surfaces. They are like the flat heads and oval heads of page 439, without screwdriver slots.

The length of a rivet means the unclosed length, measuring from the under side of the head, or the surface the head bears on, to the extreme tip. The length between heads after the rivet is driven is called the "grip."

118. Cylindrical Fastening Fits and Interferences.—Not infrequently a solid cylinder is forced into a bore hole that is too small for it to enter easily. This is done to create, purposely, a tight grip, and to set up, thereby, friction so great that no ordinary pull or twist will move the cylinder in the bore.

Naturally the metal about the hole must be strong enough to stand the stretching required, and, due to the qualities of metals (modulus of elasticity, etc.), the variation of a thousandth of an inch in an ordinary size has a marked effect on the stresses produced. Accurate workmanship is therefore a prime necessity, or the results of such fits will be very uncertain.

For ordinary sizes and materials design calculations are not needed if the draftsman uses one of the three standardized fits and calls for it by its proper name. It is assumed that the shop will have the proper tables of fits, the gages for testing and the facilities

for accurate workmanship by reaming and grinding to the thousandth and ten-thousandth of an inch.

The first of these standardize fits is the *Push Fit* or *Tunking Fit.* The bore hole for a size of 2″, for example, must be accurate within the limits of a tolerance of about one-thousandth of an inch. The cylinder should measure about a thousandth less and its tolerance is also about a thousandth. Under these circumstances there may be a clearance theoretically anywhere from zero to about two thousandths of an inch. Due to minute projections which even the best of grinding cannot avoid, the cylinder even when oiled will resist entering the bore hole and can only be induced to enter by light blows of a wooden mallet. This fit is used for such things as fitting standardized ball bearings.

The Drive Fit, also called a *Light Force Fit,* is produced if the cylinder for the same size hole as above is increased in size about two thousandths of an inch, or between such limits as 2″.001 and 2″.002. There will be an average interference of ″.0015. Interference is of course the opposite of clearance. This oversize cylinder can be driven into the hole by blows of a heavy lead or copper maul. For larger sizes a light steam hammer may be needed to assemble the parts.

The (Heavy) Force Fit would result from a further increase in size of cylinder of about ″.002. This interference, now about ″.0035, will make necessary a powerful hydraulic press for assembling the pair. The metal around the bore hole must be quite massive to withstand the bursting pressure. Wheels of large steam turbines are pressed on their shafts in this manner. So also are tires on locomotive driving wheels. The friction is so great that there is no possibility of the tire slipping on the wheel "center." Force fits can be taken apart only by applying the heat of blow torches to the outside member and using hydraulic pressure to part them.

In addition to the standardized fits there are *Shrinkage Fits* which must be individually designed in every case. The noteworthy example is the large built-up gun. In these fits a very definite tension in one part and compression in another is the aim. To assemble the parts of a gun the outside member is heated until, by careful gaging, it has been shown to have swelled up larger than

the cylinder it is to cover. Such fits once made can hardly be broken at all. Great cold applied by liquid air to the inner tube of the gun and heat to the outer hoop, aided by the pressure of an hydraulic press, may do it.

Problems

34. Name the varieties of bolt heads and nuts. Explain the use of collar bolts.

35. What is a wood screw, a lag screw, an ordnance screw? Why is the V form of thread used for fastenings? What are shrinkage fits used for? Are they standardized?

36. Explain push fits, drive fits and force fits. Which is used for tires of locomotives? Why? How can a (heavy) force fit be parted?

CHAPTER VII

REPRESENTATION OF BOLTS, NUTS, RIVETS, AND SPRINGS

119. Tables of Standard.—The tables printed in color on buff paper on pages 541–559, are the tables most needed by students and young officers of the Navy. On reaching the status of a designer, expecting to have his designs actually manufactured, one should take pains to use the actual standards in use by the manufacturing establishment for which the designs are destined. Many will be the same as these.

The point a beginner should remember is that standardized material should always be used, if possible. To call for special shapes means delay and cost. A standard part, just as good, may often be obtained from stock at a trifling cost and with no delay.

Any material resembling standard material, as given by the Tables of Standards, should be taken as standard and all minor dimensions made to conform to those in the tables unless there is a very vital reason to the contrary.

Bolts and nuts, for example, are completely standardized. We need only to know the nominal size, the type of head and nut, the length and threaded length, and the material. Assume all minor dimensions standard and ignore all imperfections of manufacture.

Whenever, in older drawings, or in replacing parts of old machinery, non-standard parts are found, change to the new standard if possible. If we should find a half-inch bolt, rough, out of round, call for a $\frac{1}{2}''$ standard bolt, unfinished. If smooth forged, true but not machined all over, call for a semi-finished $\frac{1}{2}''$ bolt. If machined all over call for a finished $\frac{1}{2}''$ bolt. Give no minor dimensions.

When called upon to draw a specific bolt or nut draw to the dimensions of the Tables of Standards, and ignore imperfection that may be found on the bolt in hand.

The bolt fits correspond to the journal fits of Art. 39 in name and number, see p. 409.

120. How and When Standardized.—The actual process of standardizing involved many halting steps. The final action occurred about as follows:

The Department of Commerce, acting through a **National Screw Thread Commission**, composed of representatives of the Army, the Navy, the Bureau of Standards, the American Society of Mechanical Engineers (A.S.M.E.) and the Society of Automotive Engineers (S.A.E.), in 1929 established *two standard screw threads for each size of bolt or screw.*

One is the **U. S. National Standard Coarse-Thread Series.** The small sizes, numbered from 1 to 12, are commonly called *Stove Bolts* and the larger or bolt sizes are the bolts long in use and formerly called *U. S. Standard Bolts.* See Table on page 547. In future, to specify them one should use the letters "**NC**" (National Coarse). It is a 60° V-thread flattened at top and bottom.

The other series is known as the **U. S. National Fine-Thread Series.** The small sizes, numbered 1–12, are known as *Machine Screws,* and have long been used under that name and specified on drawings as "M. S. No. —," etc. The full series of machine screws is shown on p. 549. The bolt sizes, $\frac{1}{4}''$ and above, are a series introduced more recently under the name of *S.A.E. Standard Bolts* for use in high-speed machinery. Fine threads make assembly tedious but are safer against shaking loose from vibration. They were formerly specified as "S.A.E. Bolts." The members of the whole series are now specified as "**NF**" (National Fine).

The full report of the Thread Commission has more than a hundred tables which give sizes to the ten-thousandth of an inch. They specify four classes of fits, called: 1, "loose"; 2, "free"; 3, "medium"; and 4, "close." These differ in the "clearance spaces" and the "tolerances" permitted. Page 547 gives all the student requires and is the result of much abbreviation and simplification of long decimals.

121. Old and New Terms Both in Use.—The new bolt standards established are binding on all departments of the federal government. Their general acceptance by manufacturers is assured, but a

long period of transition is to be expected. We attempt to put into effect as regards all new work the new standards, but for years to come we must expect to meet the old terms on old work, and in the work of conservative, long established firms, where resistance to change slows down acceptance of new terms.

When bolts, $\frac{1}{4}''$ and above, are seen on old drawings, and throughout this drawing course, unless otherwise directed, the NC series should be used.

When machine screws, quoted by number, are seen on old drawings assume them to be of the NF series.

When screws are given by size in eighths or sixteenths change to number, if less in size than $\frac{1}{4}''$. Thus a $\frac{1}{8}''$ screw is a No. 5, a $\frac{3}{16}''$ screw is a No. 10.

122. Reason for Conventional Representations.—Not only have the fastenings themselves been standardized, but the methods of drawing them also standardized and conventionalized. The reason for this is that absolutely strict application of the rules of orthographic projection results in too many lines and too difficult drawings. The representation must be simplified. For example, the helical threads should, in theory, be drawn as sinusoids, in the longitudinal views of a screw. In practice, they are converted to straight lines. Again, the chamfering of the heads and nuts creates curves, which in some cases are ellipses and in some cases hyperbolas. In practice, arcs of circles represent these curves.

The clearance space between the thread of the bolt and the thread of the nut is much too small for representation on a drawing, and the double lines for flattened tops and bottoms of threads are always ignored. We resort to labels in order to specify such matters. For example, we attach to the drawing of a bolt a label "1″—8—**NC**—3" to signify a 1″ bolt with 8 threads per inch of the National Coarse series with such average clearance as to make the fit a "medium" fit. The accuracy of the bolt and nut threads must fall within certain "tolerances" expressed in thousandths of an inch in the tables of the Thread Commission report, to pass inspection. The actual testing is by "go" and "not-go" gages.

In general bolts and nuts are drawn in a conventional manner, ignoring many details of size, and imperfections of workmanship,

depending on a label if it is rough or semi-finished. If there is no label assume that a finished bolt and nut are wanted.

Choice between methods of representing threads depends on the *size on paper,* not on the actual size of the piece.

123. Thread Pictures for Large Drawings (p = $\frac{1}{6}''$ or more).—When a bolt is drawn to a large size on paper a simplified "thread picture" is often desired. The representation is shown in Figs. 80, 81 and 82 as applied to a bolt with axis vertical and point down.

For any other position turn the page and view it as desired.

In this drawing course we prescribe thread pictures *whenever the pitch of a screw, on paper, is equal to, or exceeds,* $\frac{1}{6}''$. Thus a $1\frac{1}{2}''-6-$NC bolt, full size, and a $1\frac{1}{4}''-12-$NF bolt, drawn double

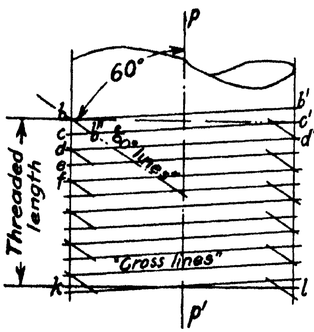


FIG. 80

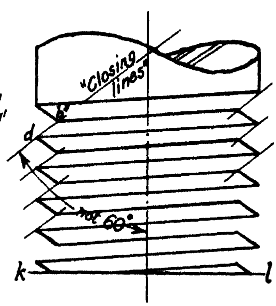


FIG. 81

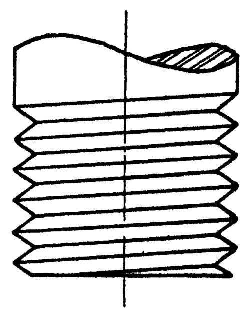


FIG. 82

size, both have 6 threads per inch, on the paper, and should be drawn like Fig. 82.

Fig. 80 shows the initial pencil work. The axis is pp' and the point is cut off squarely on the line kl. The threaded length is measured up from the end along the left edge and the line bc', drawn straight across. The thread above bc' is imperfect.

From b to k, and a little beyond, points are pricked off at *half-pitch* distances. Thus, if there are 6 threads per inch, spaces of $\frac{1}{12}''$ are laid off, giving the points c, d, e, etc. (The 1″ scale is convenient for this since the spaces which represent 1″ are actually $\frac{1}{12}''$. See p. 52, Fig. 59.)

There are now three sets of parallel lines to be drawn.

The slope of the first set, known as the "cross-lines," is found by joining the second point on the left with the first point on the right. This is the line cc'. Set the triangles to fit this line and slide one on the other, as in Fig. 81, p. 64, to draw the whole set, bb', dd', cc', etc. Go beyond the point k. As compared to the flat end, kl, the cross-lines are turned a few degrees *counter-clockwise*.

The second set of parallel lines are "60° lines." They make an angle of 60° with the axis, pp', turning counter-clockwise. The first one is bb''. Every second point on the left is used, d, f, etc., and lines drawn down. On the right d' f', etc., are used and lines drawn up. Each line on the right starts from the same cross-line as does one on the left. Fig. 80 shows the work so far finished.

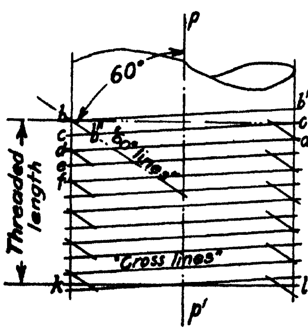


FIG. 80

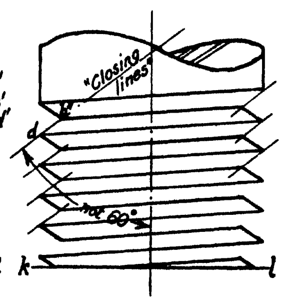


FIG. 81

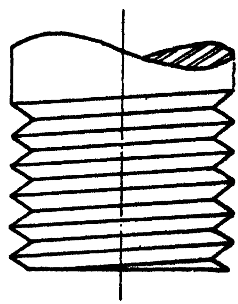


FIG. 82

Fig. 81 shows the third set of parallel lines, called the "closing lines," partially, not completely, drawn. The actual parts of the cross-lines and 60° to be inked have been emphasized and the surplus removed. The closing lines obviously close the gaps such as those still left open near the points k and l. The closing lines are not at 60° to the axis, yet if the previous work is accurate they will be parallel to each other.

Fig. 82 shows the threads as inked, with all excess pencil lines removed.

124. Bolts with Beveled or with Rounded Ends.—To make it easier to start the screwing of a bolt into a threaded hole, or nut, the point is beveled or rounded. Fig. 83 is the present or new standard beveled end.

On old Navy and other drawings many bolts are represented with rounded points, the end of the bolt before it was threaded being part of a sphere of radius equal to the nominal diameter of the bolt.

Since old standards must give way to new today we need to learn to draw the new only.

Fig. 83 is the standard beveled end of a bolt before the thread is cut on it.

Figs. 84a, 84b and 84c show three effects according to just where the flat end, *np*, may happen to come when superimposed on the thread picture such as that shown in Fig. 82. On that drawing the flat end, *kl*, might be moved up or down to any particular place and yet cause no uncertainty as to how to end the bolt. The thread is simply cut straight across.

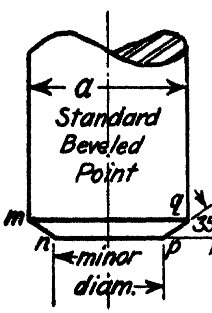


FIG. 83.

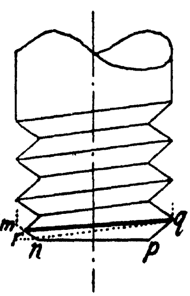


FIG. 84*a*.

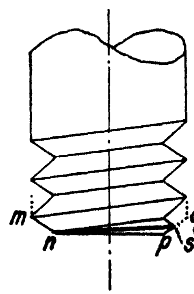


FIG. 84*b*.

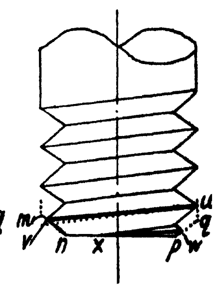


FIG. 84*c*.

Not so with the beveled end. Examine any large bolt or model of a thread closely. The projecting triangular thread will be seen to diminish as it approaches the beveled end, still keeping its triangular shape, shrinking in making its last complete turn, from its full size to nothing.

In Figs. 84a, 84b and 84c the lines *mn*, *np* and *pq* are shown at three typical positions which practically cover all possible cases.

At 84a *q* falls at the top of a thread.

At 84b *m* falls at the top of a thread.

At 84c neither one is at or near the top of a thread.

Few students will need to draw these diminishing threads but all

will need to recognize them as seen on existing drawings. They are derived by superimposing Fig. 83 somewhere over Fig. 82. Depending on just where the line *mnpq* overlaps the thread we get different results. Some lines represent metal cut away and must be discarded. These are shown by lines of dots. Some sporadic lines are added. These are made heavy. *qr* and *uv* show a thread, of full size at the right, diminishing to the left. *sn* and *wx* are threads, already much reduced at the right, diminishing to zero.

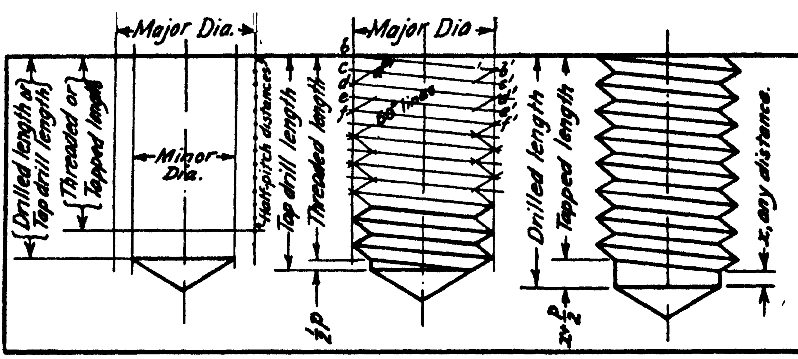


FIG. 85 FIG. 86 FIG. 87

125. The Threaded or "Tapped" Hole in Longitudinal Section. —A threaded hole is often drawn as cut open lengthwise, or "sectioned longitudinally." If the thread on paper is equal to or exceeds $\frac{1}{8}''$ in pitch, thread pictures like Fig. 87 should be drawn. The start of the pencil work is shown in Fig. 85, with center line, major diameter, tap drilled length and threaded length laid out according to the data given for the particular case. The tap drill, marked for the given size has a diameter equal to the minor diameter of the thread required. It also has a cone point, half-angle 60°, as shown.

Fig. 86 shows the pencilling of the threads, by a process similar to that of Art. 123, but reversed right for left, since the threads to be shown are those that fit the threads on the far side of a bolt of the same size. The cross lines slope at a small angle turned *clockwise,* and the 60° lines, *dd''*, etc., slope at 60° to the axis measured *clockwise.*

If the hole is a through hole the drill, of course, pierces the piece.

Its helical sharpened edges ream the hole but if it is not smooth enough the straight reamer, Fig. 89, will smooth it. The reamer has straight cutting edges slightly tapered at the end. It also is twisted through the hole. Finally the "Taper Tap" (Fig. 90), is put in a "tap-holder" and screwed by hand through the hole. The tap is made of tool steel with a slightly oversize thread cut on it.

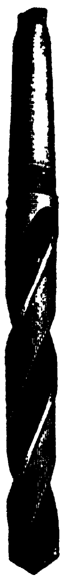


FIG. 88. FIG. 89.

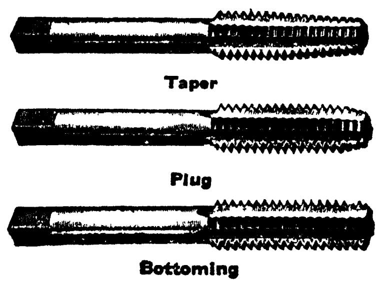


FIG. 90.

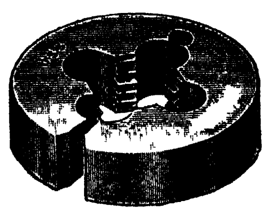


FIG. 91.

It has been fluted, tempered, ground to exact size, threads eased off where necessary and tapered. It will "feed" itself, through the drilled hole and after it has passed through leaves a perfect thread. The tap-holder is a long cross bar which can be clamped on the square end of the tap giving two handles with which to twist it.

126. The Bottom of the Tapped Hole.—If the hole is not a through hole some unthreaded part of the drilled hole must show, as in Figs. 86 and 87.

In Fig. 86 the thread is carried to the limit. On the left there is a length of tap drill hole showing, equal to half the pitch of the thread. There is none showing on the right. To produce this the taper tap would have to be followed by the "plug tap" (Fig. 90)

and that followed by the "bottoming tap." This job is a delicate and difficult and therefore expensive one. In designing avoid if possible such cases. Fig. 87 shows a hole in which the drilled length is greater than the tapped length by a fair amount. The unthreaded drilled cylinder shows a length x on the right and $x + \frac{1}{2}p$ on the left. To produce it the taper tap and plug tap must be used but not the bottoming tap if x is of fair size.

Whenever possible make tapped holes through holes, when designing. Since screw threads leak under pressure some holes must not go through. Make such holes like Fig. 87 when possible.

Fig. 91 shows the die for cutting threads on bolt ends. It too has some tapered threads to start the cutting easily. These leave imperfect threads on the bolt. The die is used in a "die-holder," similar to a "tap-holder."

127. The "Conventional" Representation of Bolt Threads of Medium Size.—In Fig. 92*a* the new standard "conventional" representation of a threaded bolt end is shown. Use 92*a* *whenever the pitch of the thread is less than* $\frac{1}{8}''$, *on paper.* As compared to the thread picture, Fig. 82, note that the **V** notches and the slant of the threads are ignored and the threads are spaced by eye only.

In practice space them about one-eighth of the radius of the bolt apart and let every other one end about one-fifth of the radius from the outer edges. Do this without measurement of any kind.

The threaded length of a bolt is always taken to include the beveled or the rounded end. Since slope is not shown a left-hand thread must be labeled as such. In fact all threads are being labeled more and more to distinguish **NC** and **NF** threads.

In Fig. 92*b* an old method is shown. It will be seen on many drawings still in use. Do not repeat it but change to 92*a*.

128. Representation of Very Small Threads.—In drawings in which the diameter of the bolt is $\frac{1}{4}''$ or less, on paper, the shorter lines of Fig. 92*a* are generally omitted. (See 92*c*.) This avoids crowding the lines and very frequently medium lines (No. 6 of page 543), 0".010 thick, are used instead of heavy lines (No. 1).

129. Representation of Hidden Interior Screw Threads.—On page 546 a summary of methods of drawing threads is shown. In Fig. 5 there are four dotted lines on the front view, projected down

from the plan. They mark the major and minor diameters of the thread. The outer pair are accurately scaled since they show the nominal size of the bolt. The inner pair are often judged by eye.

When circumstances are such that no error can arise the inner pair or both pairs may be omitted.

130. End Views of Bolt Threads.—The end view of the point of a bolt is a full circle for the nominal size and a dotted one for the minor diameter of the thread. (See 2 and 7 of p. 546.) The end view of an open threaded hole is the reverse. (See 3 and 10 of p. 546.)

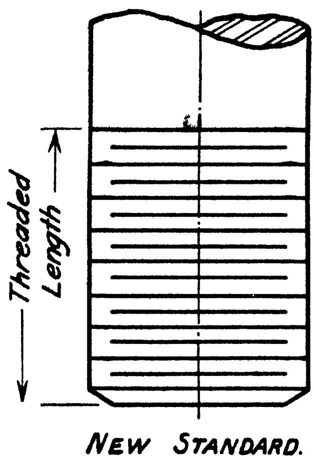


FIG. 92a

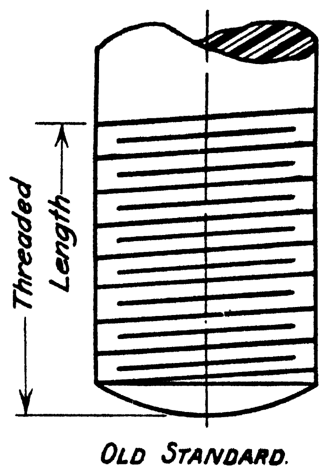


FIG. 92b

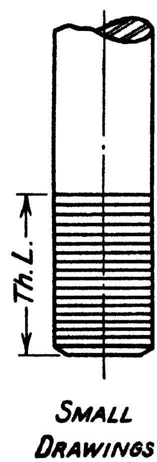


FIG. 92c

131. Excess Threads on Bolts.—Nuts jam badly on imperfect threads, and all bolts have such. Hence the rule: **Always allow two or three more threads than will be used when bolts are set up.**

132. Imperfect Threads on Stud Bolts.—The exception to the rule is for stud bolts, which are headless bolts threaded at both ends. One end is screwed forcibly and permanently into a tapped hole with little or none of the imperfect thread projecting. (See **L** on p. 473.) A special tool, a "stud-driver" is used. The imperfect threads screwed into the tapped hole create great friction around the rim. To assure this friction at the place desired the point of the bolt must not touch the bottom of the bore hole. (See stud, **n**, p. 501.)

Note that the nut on top, though screwed up tight, does not use all the upper threads, as can be seen just above the letter **n.** This is the nut that can be set up or loosened at will, with no danger of loosening the stud at the bottom.

133. Representation of an Hexagonal Head or Nut.—Most nuts are "chamfered" on top, and many are chamfered top and bottom. This chamfering is sometimes conical, sometimes spherical. The method of *representation* is shown in Fig. 93. On commercial nuts chamfering is apt to be much in excess of the amount here repre-

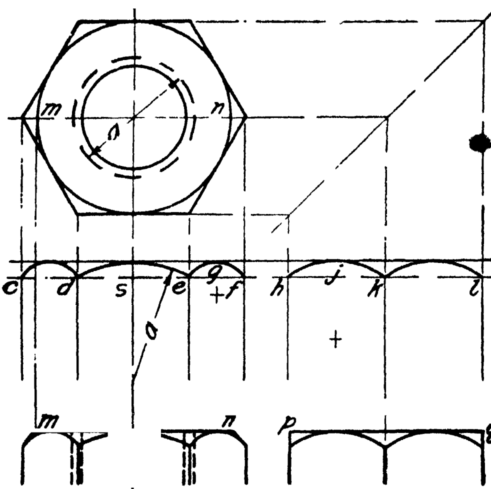


FIG. 93.

sented, but, as we are conventionalizing the drawing, we adopt a standard method requiring the minimum of work.

The plan represents a nut. The three circles are the minor diameter of thread, nominal diameter of bolt and the chamfer circle. The last is taken from column 9, p. 547, the "wrench size" for the given bolt. Around it is circumscribed a hexagon, **with long diameter horizontal,** except for very good cause. Just below the plan is shown the pencil work for front and side views. Note the radius *a* on the front view which is equal in length to the diameter *a* on the plan. With center on the V. C. L., with this

radius, the arc *de* is described. This arc, by cutting the inner lines for the edges of the hexagon, as projected down from the plan, defines the points, *d* and *e*. Through *d* is passed the lower horizontal line which cuts the outer edges for the hexagon at *c* and *f*. Carried across to the side view this line defines also the points *h, k* and *l* on the edges of the hexagonal prism. Let us take points *e* and *f* and estimate a point *g* half way between on the upper line. Pass a circle through these three points by the trial and error method of Art. 121 on page 94. When this has been done use the same radius for the arc from *c* to *d*. If the work is accurate it will be properly tangent to the upper line. In the same way pass an arc through *h, j* and *k* and use the same radius for the arc from *k* to *l*.

The actual front and side views below show how the ink work looks. For very large sizes, project from *m* and *n* on the plan to the front view and draw lines to the extreme corners. If the drawing shows the nominal size as 2″ or more, on the paper, put the corners on. **If less than 2″, on paper, omit the corners m and n.**

For this construction remember always to use the nominal diameter for the first arc drawn on the front view. It does not vary with the axial length of the hexagonal prism. The same chamfering appears on the standard nut, the jam nut, the lock nut or any hexagonal nut.

Nuts which are not chamfered on the bottom also frequently have "washer faces" as on the drawing over columns 15, 16 and 17 of p. 547. This is not drawn ordinarily.

The square corners, p and q of Fig. 93, must never be omitted from the side view of an hexagonal nut or bolt head, or it may be mistaken for the corner view of a square nut. This difference can be seen in Fig. 78, p. 473, by comparing the nut on **L** with the nut **W.**

134. Representation of Hexagonal Head or Nut without a Plan View.—Bolts and nuts are so well known that frequently one view, a longitudinal view, is considered enough to represent one. In such a case no plan is drawn. The method of drawing differs only in the start. Instead of drawing the chamfer circle from column 9 of page 547, the figure in column 10 must be used. It is divided into four parts for locating the edges of the hexagonal prism on

the front view. Thus in Fig. 93, *cf* is the value in column 10. $cd=ds=se=ef=\frac{cf}{4}$. The value *cf*, in hundredths of an inch in Column 10, is a minimum value. It is not perfectly exact at best, so slight inaccuracies here are to be expected. The rest of the drawing is as before.

135. The Square Head and Nut.—In Fig. 94 we have a square nut with side and corner views. Figs. 95 and 96 show a square-

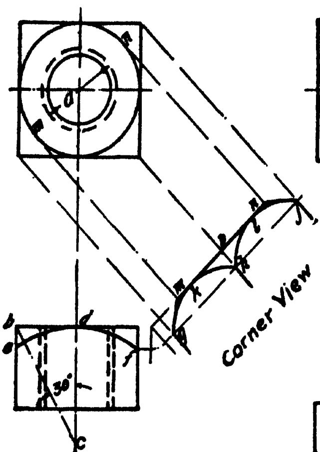


FIG. 94.

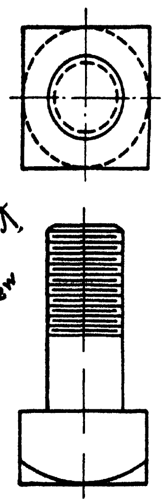


FIG. 95.

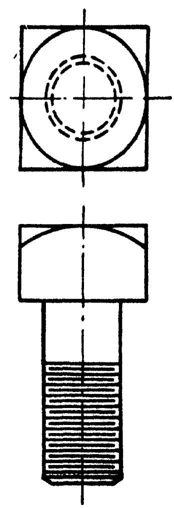


FIG. 96.

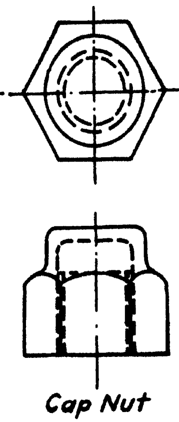


FIG. 97.

headed bolt in two positions. In Fig. 95 the chamfer circle is broken, in Fig. 96 the circles for tops and bottoms of threads are both broken.

The method of drawing is shown by Fig. 94. Use the wrench size in Column 9, p. 547, for the diameter of the chamfer circle on the plan. Pass vertical and horizontal lines tangent to it, to form the square prism. On the front view lay off the axial length of the prism from Column 13, "Height of Nut." From a corner, *b*, draw *bc* at 30° with the axis *dc*. With *c* as center and *cd* as radius, describe the arc *edf*. Finish the work as shown.

The corner view is not often wanted. It may be required, however, to show that the nut has room to turn in a crowded space. In that case draw the corner view of which a little is shown. Note that the distance *ph* is the same as *be*. *h* establishes the position of the line *ghj*, and an arc of a circle is put through *g*, *k* and *h*, by trial and error methods and the same radius used for *hlj*. *m* and *n* on the plan project to *m* and *n* on the corner view. These corners on the corner view are usually large enough to be drawn without fear of blotting when inking. They are usually shown.

136. The Cap Nut.—Fig. 97 illustrates a cap nut, to draw which the chamfer circle is penciled in to aid the construction of the hexagon and of the three arcs on the front view, but is not inked because not an actual edge as on usual forms of heads and nuts.

137. Standard Carriage Bolts.—See **V** of Fig. 78. The carriage bolt has for head a slice of a sphere. The thickness of this head is half the nominal diameter of the bolt. The radius of the sphere of which the head is a slice, is equal to the wrench size for the same bolt. Thus for a $\frac{1}{2}''$ bolt we find $\frac{3}{4}''$ under Column 9. This is the radius of the sphere. The axial thickness of the head is $\frac{1}{4}''$. The square neck is given a length equal to one and a half times the nominal diameter, or, for the $\frac{1}{2}''$ bolt, a length of $\frac{3}{4}''$. The length under head and the threaded length are made to any size desired as in other bolts.

A square nut is common with a carriage bolt, and a washer is usually used under the nut.

138. Method of Representing the Square and Acme Threads.—The representation of square threads on a drawing is similar to that of a V, but more simple. The slant lines are drawn, spaced at half-pitch distances, and the slope of any one is also half the pitch. Instead of any 30° lines, the lines for bottoms are drawn at half-pitch distances from the edges. Pains must be taken to have the bottoms of the threads on one side agree with those on the other side, or an impossible result follows. Fig. 98 is typical of the pencil work, and Fig. 99 of the finished work in ink. Note that the threaded length is on the short side, since the thread is imperfect beyond that point.

The thread is generally represented as ending on the other side

of the bolt as is also usual when drawing V-threads. In Figs. 100 and 101 it is shown ending on the near side of the bolt, and, in the latter figure, in a small bore hole. Follow Fig. 99 in preference.

The **Acme Thread** has replaced the square thread in practice. It is a square thread modified by turning the sides of the square $14\frac{1}{2}°$ about their middle points, resulting in a profile like the worm thread on page 302. The standard threads per inch are given in Column 18 on page 547, but finer threads are often used. Acme threads are much used on operating mechanisms, such as lead screws of lathes. They are drawn as if square threads, but are always labeled "Acme threads, . . . per inch."

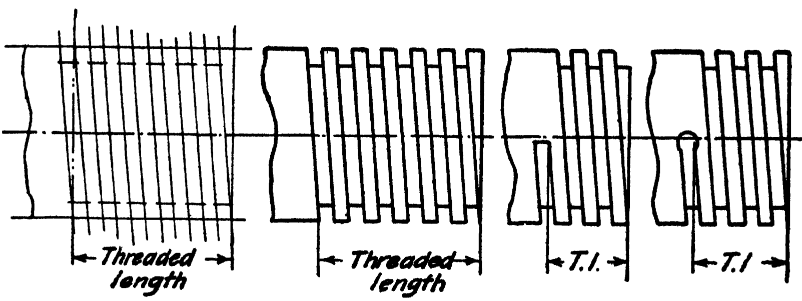


FIG. 98. FIG. 99. FIG. 100. FIG. 101.

The **Sharp V-Thread** is drawn like the standard flattened 60° V-threads. It is used for special purposes and is cut on the lathe, not by dies and taps. The pitch is always finer than **NC** or **NF** threads and the number per inch should be marked by a label. The usual pitch is about as follows:

Outside diameter...	$\frac{1}{2}''$ — 1″	— $1\frac{1}{4}''$	— $1\frac{1}{2}''$	— 2″	— $3\frac{7}{8}''$	4″ and above
Number of threads.	20	16	14	12	10	8

139. Representation of the Square Helical Spring.—Helical springs are made by winding wire around a cylinder to the form of a helix and then withdrawing the core cylinder. The wire is often square in section, in which case the resulting shape is that of a square screw thread with no core cylinder. The problem of representing springs on drawings is similar to that of representing screw threads.

A screw thread has a fixed axial length. A spring is made of one length called its "free length" and is then generally compressed into a shorter length. Thus the pitch is variable, and since the student is first likely to see a spring shown on a drawing in its compressed form and be himself required to show it on a detail drawing of its free length, he finds a new difficulty in drawing it, and some calculation to make first.

In Fig. 102 is shown a spring of square section, *a*, of three turns, and length, *l*. A spring is regularly described in words by naming

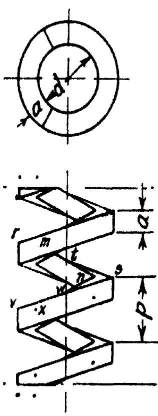


FIG. 102.

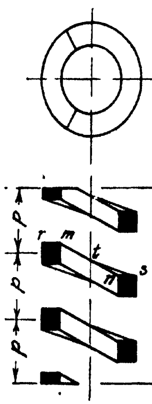


FIG. 103.

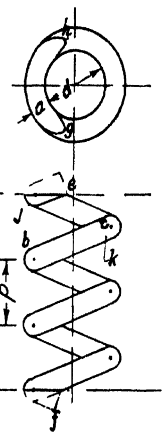


FIG. 104.

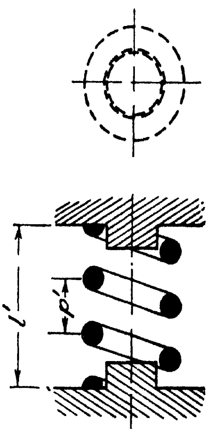


FIG. 105.

its section, its core diameter, *d*, its length, *l*, its number of turns, and material. The figure shows a plan and a front view. The helices are always replaced by straight lines. Moreover no slanting lines for concealed edges of helices are drawn, obeying the general rule for all threads in this.

In Fig. 103 we have an easier representation. This is a plan and a front-view-in-section. On one side of the section we have the fact that we have exactly three turns accentuated by having the center of one square section on the top line and another on the bottom. Since the pitch is the distance axially from one turn to another, taken from corresponding points, we see the three pitch distances here very easily. Thus we have two half squares and two

full squares on the left and three full squares on the right half way between as regards axial distances. These squares are drawn in pencil first. If the section is small we may "hatch" in solid black, whatever the material. In representing the helices on the section we join inner corners of the squares, as *mn,* forming a system of parallel lines sloping according to whether the spring is a right-hand one, as is usual, or a left-hand one. We next join outer corners, but the large helices so represented are only half visible. Thus the line joining *r* and *s* is drawn only from *s* to the center line at *t*. These lines, of course, represent the back half of the spring.

If necessary to draw the side view and not the section our process is reversed. Return now to Fig. 102. Draw the squares and half squares just as for Fig. 103. Dots for the corners such as *m, n* and *x* are shown in the figure indicating the missing corners of the half squares. We join first the outside corners such as *s* and *v,* in direction to represent the front half of the spring, and draw all parallel lines. We then join such corners as *n* and *x* to represent the near halves of the inside helices, but we draw only the visible parts such as *nw, w* being on the center line. We now draw the helices for the back half, just as in Fig. 103, omitting any part which disappears behind the work already completed, as we want no broken slant lines.

Springs are always faced off top and bottom by planes perpendicular to the axis. These planes give radial lines on the plan which are in practice often ignored.

140. The Round Helical Spring.—In Fig. 104 is shown a spring of round section, otherwise exactly like that of Fig. 102. We first draw on one side two circles of diameter *a* and two half circles. The centers are shown by dots and are on lines projected from the plan from a circle of diameter, $d+a$, half way between the core diameter and the outside diameter. In pencil the circles are complete circles. In ink they are but half circles and the cross lines are tangents to the half circles. Of course lines *bc*, etc., are drawn first and those like *jk* drawn, omitting parts that disappear behind finished work.

The flattening at the top creates an intersection on the plan shown by the curve *gh*. This is omitted in practical drawing. It should be noticed that to make this spring nearly three and a half turns of wire are needed, namely from *e* to *f*, as shown by the phantom lines on the front view. Point *e*, when projected to the plan, is at *g* and *f* is under the point *h*. The squaring off at top and bottom has reduced this to exactly three turns, on the scientific definition, but practical men are inclined to speak of springs by the total turns before grinding off the ends. Be on guard against confusion here.

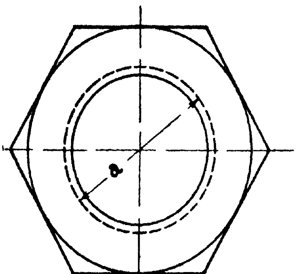
141. Free and Compressed Lengths of Springs.—In Fig. 105 the same spring as in Fig. 104 is shown, but it is now compressed between two machine parts to a length, l'. The pitch, p, is diminished to p' in exactly the same ratio of decrease. We have shown a section-on-the-front-view here so the slant lines cross in the direction for the back halves of the turns. The pieces which compress it are shown with "spring centering bosses," a little smaller in diameter than *d*. They are regularly used if there is reason to fear that the spring will get canted to one side or otherwise out of alignment.

A problem often arises in the following form. An assembled drawing, like Fig. 105, shows a spring compressed and a label gives the information about its free length in this fashion: "$\frac{1}{8}''$ round steel spring, $\frac{7}{16}''$ core diameter, free length $1\frac{1}{8}''$." If the turns are given correctly (with no error due to the facing of the ends) or are shown accurately on the drawing, then p, the pitch, when free, is simply l divided by the number of turns. The difficulty is all in a correct determination of the number of turns, which will not often be a simple integer as in these examples.

142. The Rivet, Before and After Driving.—Classified as permanent fastenings are the rivets. The "Boiler Rivet" of p. 550 is used for work of high class for vessels holding great pressures. The plate holes are drilled and reamed fair, if not already in line, and are slightly countersunk.

A point to remember about rivets is that they are put into holes $\frac{1}{16}''$ larger in diameter than themselves. Rivets of $\frac{1}{2}''$ size and above are heated to a bright red or white heat from point almost to

the head. Heavy pressure by a riveting machine or blows from heavy mauls on the "dolly" shorten or "upset" the rivet until it fills all the extra space around its length and forms in addition a new head. Thus the $\frac{3}{4}''$ rivet becomes $^{13}/_{16}''$ in diameter after driving, but is still called a $\frac{3}{4}''$ rivet.



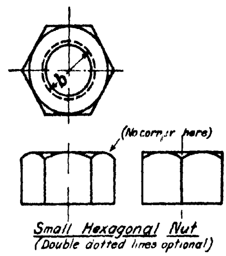


FIG. 107.

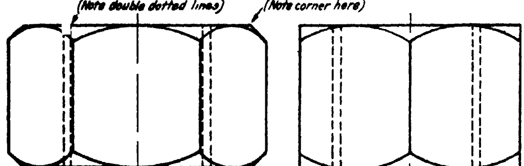


FIG. 106. Large Hexagonal Nut. (2" or over on paper)

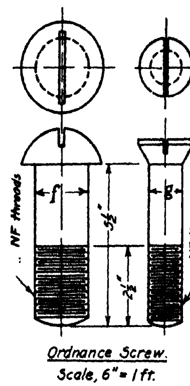


FIG. 109.

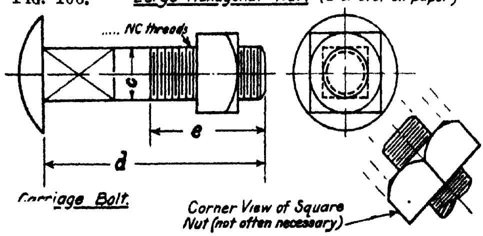


FIG. 108.

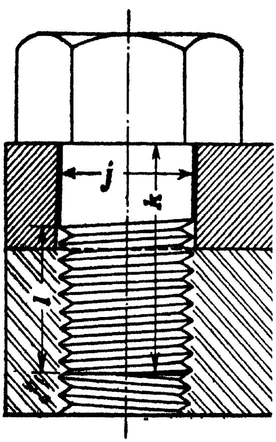
The sum of thicknesses of plates to be riveted together is called the "grip." The length under the head of the rivet must supply material to fill the extra space in the grip and to form the new head. The proper length for a given size of rivet and for a given grip is found from the graphical table on p. 551.

Rivets for structures, such as buildings, bridges and ships, differ from boiler rivets which are used for pressure vessels. They are

rougher and the rivet holes are not drilled but are punched undersize and reamed out to required size after the plates have been assembled and temporarily bolted together.

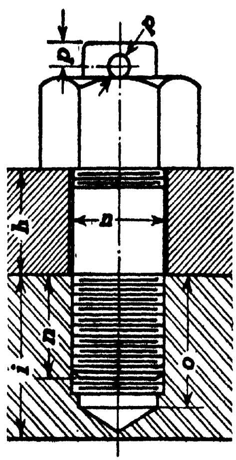
We end this chapter with some illustrations of correct representation of standard fastenings, Figs. 106-112, here shown about half size. Because threads show under the nuts of Figs. 111 and 112, no dotted thread lines (single or double) are needed.

Bolts and nuts are never sectioned longitudinally. Special threaded pieces may be so sectioned, however. In such cases follow Fig. 13, page 545, using freehand "v" threads for small threads, using instruments for any pitch greater than $\frac{1}{6}''$ as drawn.



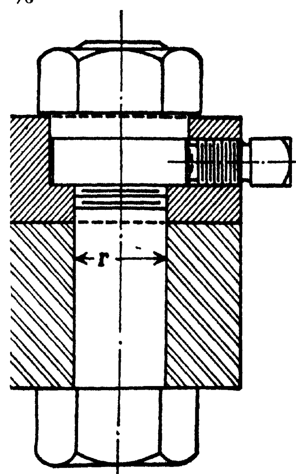
Tap Bolt

FIG. 110.



Stud Bolt with Point Drilled for Split Pin

FIG. 111.



Bolt with Lock Nut and Set Screw

FIG. 112.

Problems

37. Give the old names of parts of the **NC** and **NF** series of bolt threads. What is a drill, a tap drill, a reamer, a taper tap, a die?

38. When are excess screw threads provided? When are they avoided? How draw the front view (no plan) of a hexagonal nut?

39. If you have a drawing of a helical spring as compressed and are given its free length how do you calculate its free pitch? What distinguishes rivet holes for boilers from those for hulls of ships?

40. Complete the drawing of the ordnance screw shown in Fig.

113. This requires the completion of the thread by standard method No. 6 of page 546, and it requires in the plan the determination of the length of the screw driver slot. To do this imagine a horizontal plane cutting the head at the bottom of the slot. Use arcs of the circle of the size so determined to end the slot on the plan.

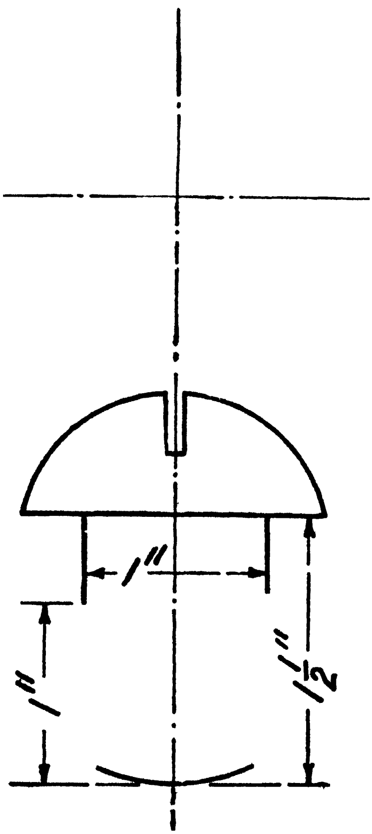


FIG. 113.

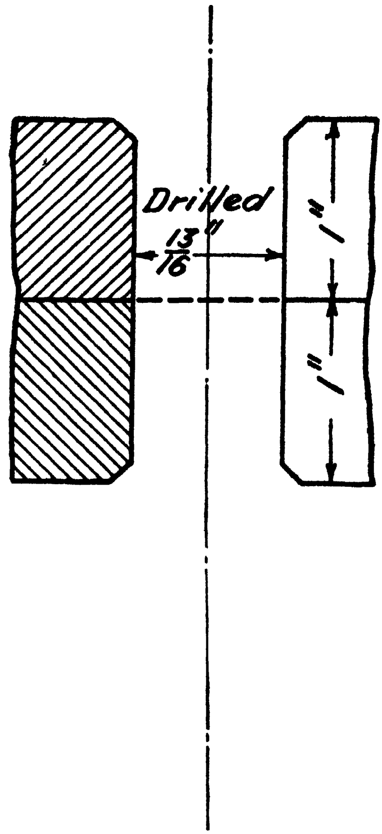


FIG. 114.

41. Fig. 114 is an incomplete drawing of two metal plates. Complete it by filling the drilled hole with a boiler rivet of proper size taking the dimensions of the head from p. 550. Represent the rivet closed, like *K* of p. 473. Show also its length and diameter before closing (when in the condition shown by *M* of p. 473) by construction lines after using the chart, p. 551. to determine its length.

CHAPTER VIII

STANDARD PIPE FITTINGS

143. Varieties of Pipe Fittings.—There are many varieties of pipe fittings, each for its own appropriate service and in connection with its particular kind of pipe. There are in consequence many standards. For example, there are cast iron gas and water mains, with their fittings; wrought steel pipe for plumbers, with malleable iron and mild steel fittings attached to the pipes by screwed joints. There are also flanges for steel pipe to be screwed on, or others to be welded on. There are copper steam pipes, with bronze flanges brazed on, and many other types. It is the engineer's duty to know the proper kind to use for each particular service.

The aim of this chapter is to call attention to one or two varieties of fittings, and to teach the use of the Tables of Standards for those one or two varieties. We will discuss first the Tables of Standards on pages 552-559, Nos. 12-22, in their order, giving any necessary explanations.

144. Standard Pipes and Pipe Threads.—The ordinary pipes used for domestic plumbing, and a great deal of small pipe work, were formerly made of wrought iron. Usually they are of soft steel now, though often called "iron pipe."

They have been standardized in three weights: (1) Ordinary or "Standard" pipe, (2) Extra Strong, and (3) Double Extra Strong. The table for these pipes is No. 12 on page 552.

All the pipes of the same size have the same standard pipe threads. These threads are very much finer than the threads on bolts, in order to avoid cutting too deeply into the thin walls of the pipe.

Since the outside diameter of a pipe is of fixed size, to permit cutting the standard threads, and since thicker walls are needed to withstand greater pressure, the inside diameter of the pipe decreases in size. As a consequence, the pipe known as a 1″ pipe, for example,

has an outside diameter of 1″.31, but has an inside diameter of 1″.048, 0″.951, or 0″.587, according to whether it is Ordinary, Extra, or Double Extra. The 1″ appears in the *name only*.

The pipe thread, also, is cut on a slight cone. It is a 60° V-thread, slightly rounded top and bottom. The cone decreases in diameter $\frac{1}{16}$″ for an inch of length. By the "Briggs Standard," there are a number of perfect threads followed by six imperfect ones, as the thread dies away. This conical feature was adopted in order to make it an easy matter to screw the pipes and fittings together until the joint becomes steam and water tight.

The typical conical thread on the end of a pipe is shown in

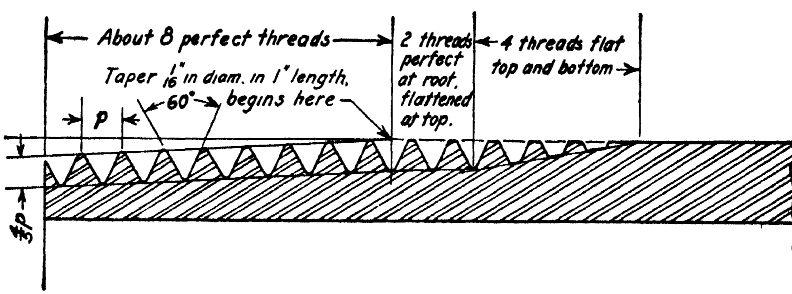


FIG. 115.

Fig. 115. The fittings are threaded on a hollow cylinder. Sometimes, however, on a hollow cone of less taper than the pipe.

In making an ordinary joint the end of the pipe is painted with red lead or black lead paint, and the fitting screwed on until the pipe fitter finds it difficult to turn further, using a wrench with the ordinary leverage.

Because the conical thread is regularly used on pipes as the standard and is well understood by mechanics, it is unnecessary to show the conical feature on drawings. It is enough to represent the thread as a plain or cylindrical one and to attach some label such as "1½″ **NPT**." or "Tapped for ¾″ **NPT**." **NPT** means National Pipe-thread, Tapered.

We see from p. 552 that pipe threads never exceed ⅛″ pitch. It is

logical, therefore, to show them by the "conventional method." See 8 of p. 546.

In 23 of p. 546 the concealed pipe thread is represented by double dotted lines, like a bolt thread. Pipe threads are usually labeled NPT but this one is labeled **NPS**, meaning National Pipe-thread, Straight. Occasionally NPS threads are wanted. The slight taper on the outside of 8 of page 546 is shown only when there is some reason to fear that an NPS thread might be used, when an NPT is required.

On small drawings the shorter cross lines are omitted on pipes as on bolts. See 16 of page 546. Another representation of sectioned pipe threads, *allowed only on small drawings*, is shown at 22 of page 546. The *V*'s are put in freehand with lettering pen, and the size is estimated.

145. Decimal Equivalents of an Inch.—The necessity for passing from the decimal to the octagonal subdivision of the inch, and vice versa, frequently makes itself felt. For example, one may wish to express the actual inside diameter of a standard 2″ pipe as a fraction. For this the Table of Decimal Equivalents, on page 552, is a convenience. The bore of this pipe is given as 2.″067 in Table No. 6. Compare this figure with the second column of Table No. 7. We find ″.062 to be the equivalent of 1/16″ and therefore put down the pipe bore as almost exactly 2 1/16″.

This table is convenient on many occasions. Do not forget it.

146. Birmingham Wire Gauge.—Thicknesses of wires, sheet metal, particularly copper and brass plates and the pipes made from them, are often quoted by numbers thus: "Thickness No. 5, B. W. G." This refers to the table of the Birmingham Wire Gauge given as Table No. 14, on page 552. By reference to this table No. 5 is seen to be ″.22 thick.

The designer aims to use standard commercial sizes of all common materials. He can avoid calling for unusual thicknesses if he takes his sizes from this table as much as possible, instead of quoting them fractionally or decimally.

147. Standard Screw Pipe Unions.—This table, No. 15, page 553, and the following are examples of standard screw pipe fittings. We have no need of a complete set of such screw fittings, but must

know something of their nature. Ordinary small-sized piping in buildings is erected by screwing a pipe to a fitting, then another fitting to a pipe, then another pipe, etc. A short hollow pipe, threaded on the inside, is called a coupling, and is used to join straight pieces of pipe. In order not to have to unscrew a great many pieces, when a part is to be removed, a screw pipe union is often inserted instead of a coupling. The union is of three parts, **1**, **2** and **3**, as shown in Table 15. **1** and **3** screw on to the ends of the pipes to be connected, **2**, which has been slipped on the pipe ahead of **1**, then screws on to the outside thread of **3**, drawing **3** up to **1** until the conical end of **1** is forced into the hollow cone of **3**, making a steam-tight joint. These conical surfaces have been ground smooth and the tool marks and other roughnesses seen on ordinary lathe work removed.

148. Standard Screw Elbows and Tees.—These fittings, Table 16, on page 553, are for pressures up to 200 lbs. per square inch. They are castings of a very good grade of cast iron, but have been "malleabilized" by a process which virtually converts the cast iron into tough and malleable steel. The cross lines are the conventional representation of the hollow threads, ignoring taper.

Pipes and fittings are occasionally threaded with left-hand threads, but, of course, such a variation would be noted by a label on the drawing.

The elbow, for turning a right angle, is frequently called an ell.

These fittings are for the "steam fitter" to use with "extra strong" pipes, tabulated on page 552, Table 12.

The student will see much lighter fittings of galvanized steel to be used with water pipes in which the pressure does not exceed 100 lbs. They are smooth on the outside, having no raised rims.

149. Standard Flanged Ells and Tees.—The flanged fittings and pipes shown on page 554 are much more used on shipboard than are screw fittings. Each piece of pipe is fitted at each end with a flange, and the ells and tees are flanged. The flanges have a row of bolt holes spaced equally around a circle, called the pitch circle. When mating flanges are brought in line, with a gasket between them, and the bolts inserted and set up, the joints are made steam tight. The advantage over screw fittings is that a defective

part may be taken out by "breaking" two joints. With screw pipe and fittings it is often necessary to take down a considerable length of line to get at a bad part.

At the top of page 554 the shapes of the common fittings are shown. Letters indicate dimensions whose values depend on size, material and pressure to be resisted. Let us first consider the shapes and some general principles.

The 90° Ell or Elbow. When a pipe line makes a turn of 90° an ell is commonly used. The center lines of the straight stretches of pipe meet at a point here marked **a.** The distance from **a** to the "face" of a flange, **B,** is called the "length of the nozzle" or the "offset." The dimension **C** is the radius of curvature of the curved center line of the pipe bend and when the proper value is known it is applied to the straight center lines by the method of p. 90, like a fillet. Therefore the location of the actual center is not marked. In casting an ell the core used is shaped like a quadrant of an anchor ring with straight cylindrical extensions of the proper length.

Each opening to a fitting is called a "nozzle" and an elbow has two nozzles at right angles to each other, both of the same length, **B,** and both ending in flanges suited to the size and pressure.

A Reducing Elbow is one which changes its size in making the 90° turn. It might start as a 3″ pipe and end as a $2\frac{1}{2}''$ pipe. In that case the dimensions of the flange on the $2\frac{1}{2}''$ branch would be smaller than those of the 3″ branch. However both branches would have the length, **B,** as taken from the larger size.

The Tee. The common Tee has three equal nozzles all of the same length, **B.** The drawing shows no dimensions lettered **A, K, M, N** or **O,** which were omitted to make the drawing clear. Take them as the same as for the ell. Note the fillet **J,** on the outside, at the junction of the "side outlet" and the "run." To preserve constant thickness the inside is filleted with a radius, **J + K.**

The Reducing Tee. One of the nozzles, or two of them, may be of reduced size. In that case the reduced nozzle or nozzles have reduced dimensions as required except that the nozzle length, **B,** remains the same and is that tabulated for the largest nozzle.

The 45° Ell. This fitting is used when a pipe line makes

a deflection of 45° in its direction. The two nozzles have a length **D**, but the offset or distance of the center of one flange from the plane of the face of the other is a larger dimension, **E**, and the deflection to one side of the original centerline of the pipe is a smaller dimension, **F**. Dimensions missing on this drawing are taken from the 90° Ell, of course.

The Long Radius Ell. This elbow has a much greater offset, **G**, and a larger radius of bend, **H**. It is used when it is desired to reduce the friction of flow of the fluid in the pipe, or when, in a crowded space, it helps one pipe line to clear another one.

Fitting with Bulkhead Flange. The fitting shown in the figure is a 90° Ell with a Bulkhead Flange. One flange of any Tee or Ell may be made a bulkhead flange. To do this the flange is extended to a much larger diameter. The extended part is almost always thinner than the plain flange. Its thickness is lettered **P**.

The bulkhead flange is used where a pipe line pierces a bulkhead (or a deck) and the added ring is drilled for a second row of bolts. The bulkhead has a circular hole cut about a quarter of an inch larger than **M** (the diameter of the standard plain flange) and is drilled for the set of bulkhead bolts. There is one dimension changed when the flange is applied to a tee or ell but not changed when applied to a 45° ell or a long radius ell. The length of the nozzle **B** is increased to a larger size, **W**, to give room for the wrench to screw the nuts on the bolts.

Between the bulkhead and the bulkhead flange a "gasket" is fitted to make the joint water tight. The gasket is cut from a sheet of thin, flexible and compressible material, in the form of a ring whose outside diameter is **Q** and inside diameter about **M** + ¼″. Drawings usually show no gaskets. The thickness may be only a few thousandths of an inch, or as much as ¼″. The choice of gasket material depends on the particular service required. Some are of copper or other soft metals, generally formed with concentric corrugations. Others are of hemp, asbestos, graphite, red lead and many other materials suitably combined. It is enough to put a notation on a drawing where a gasket is needed, and not to attempt to draw it.

Certain dimensions of the fittings are dependent on the size alone

and do not vary with the material or pressure within the pipe. Columns 2 to 10, on p. 554, show these dimensions. Column 1 gives the "nominal size" or "wrought pipe size," the same series of names as on page 552 for "commercial" pipes. Regard these as names only. The 3″ pipe, for example, and the 3″ fittings to go with it, no matter of what material made, or for what pressure, do not have an actual 3″ diameter outside or inside.

Pipes above 10″ are often named from their actual inside diameters but this is not invariable. To be definite it is well to add the letters I.D. (Inside Diameter). A mistake is then hardly possible.

150. Flanged Cast Iron Fittings.—Columns 11 to 25 of page 554 give the particular dimensions of the fittings made of cast iron suitable for pressures from 0 to 100 lbs. gage per square inch. Sizes of 8″ and above, however, are limited to 50 lbs. pressure. **K** is the thickness and **L** the outside diameter of the pipe between the flanges. **L** is of course equal to **A** + 2**K**.

Columns 13 to 18 give the dimensions of a flange. **O** is the "pitch circle" on which the bolts are spaced. Column 18, labeled "chord," is the straight distance between centers of bolt holes and is useful for setting the dividers to space the bolts equally around the pitch circle.

Columns 19 to 25 give the dimensions for the bulkhead flange for these fittings.

Cast iron fittings are much used with standard commercial pipes (p. 552) but because of their weight are not used on naval vessels.

Columns 25 to 29 are dimensions of "extra heavy" cast iron fittings suited to pressures of 101 to 200 lbs. and they too are used with "extra strong" commercial pipe.

Adjacent flanges are connected together at their nearest points by a rib. This is well shown on page 396.

151. Copper and Brass Pipes or Tubes.—For many purposes copper or brass pipes are admirably suited. Salt water must often be pumped overboard from the bilges and copper pipes are not corroded by salt water as steel pipes are. Copper may be used for low pressure steam, not exceeding 50 lbs. gage pressure. Copper pipes are easily bent around curves, saving the use of many fittings. Seamless drawn copper and brass pipes are pulled through a die in

such a way as to have no longitudinal seam. On p. 555 columns 22 to 27 give the dimensions of such pipes for (nominal) sizes of $\frac{1}{4}''$ to $10''$, listed in column 1. Column 22 gives the outside diameters and columns 23 to 27 give the thicknesses for pressures of 100, 200, 300, 450 and 600 lbs. They are computed by the formula,

$$T = \frac{(\text{Gage pressure, lbs.}) \times (\text{Diameter, inches})}{2(4000 + \text{Gage pressure, lbs.})}$$

If other pressures were required other thicknesses could be computed but the tabulated thicknesses are the usual ones.

Of course the inside diameter of any particular pipe is the outside diameter less twice the thickness.

Pipes larger than $10''$ are made of sheet copper in long strips rolled into pipe form and the longitudinal seam "brazed," i.e. soldered with "hard solder" or "spelter." Spelter is a variety of brass having a low melting point. Hence the verb, to braze. Silver solder is a variety of hard solder now much used.

These **Brazed Copper Pipes** are tabulated in the lower right corner of page 555 up to $15''$ size. The full table, of which this is only a sample, continues to $36''$. Pressures allowed do not exceed 300 lbs.

These large sizes are always named from their inside diameters which are exact. This is in contrast to the sizes from $10''$ down whose outside diameters are standardized and whose nominal sizes are artificial names.

152. Flanged Composition Pipe Fittings.—The bronze fittings designed to be used with copper and brass tubes and pipes are shown also on page 555. The dimensions for pressures up to 100 lbs. are tabulated in columns 6 to 13. Those for pressures from 101-400 lbs. in columns 14-21. The larger sizes, from $11''$ I.D. to $15''$ I.D., are used with brazed copper pipes. The second series has only sizes for $11''$ I.D. and $12''$ I.D., and they and their pipes are limited to 300 lbs. pressure, not 400.

153. Composition Flanges for Copper and Brass Pipes.—The table on page 556 lists the dimensions of flanges cast in bronze for the pipes of page 555, columns 22 to 27. The word Composition in the title is a general one, covering all alloys in which copper predominates.

The flange casting is machined to an accurate plane face, bored for bolts, spotfaced on the back of the flange and bored and counterbored to fit the inside and outside diameters of the pipe. A 45° bevel, 1/32" deep is also bored. The flange is put face down, the pipe inserted in the counterbore and both are heated to a red heat by a blow torch. Silver solder, with a flux to prevent the formation of oxides, is melted and fed into the 45° bevel until it fills all cracks.

Two such pipe ends are shown in Fig. 116 (at about one-third size), ready to bolt together. To emphasize the fact that no 2½"

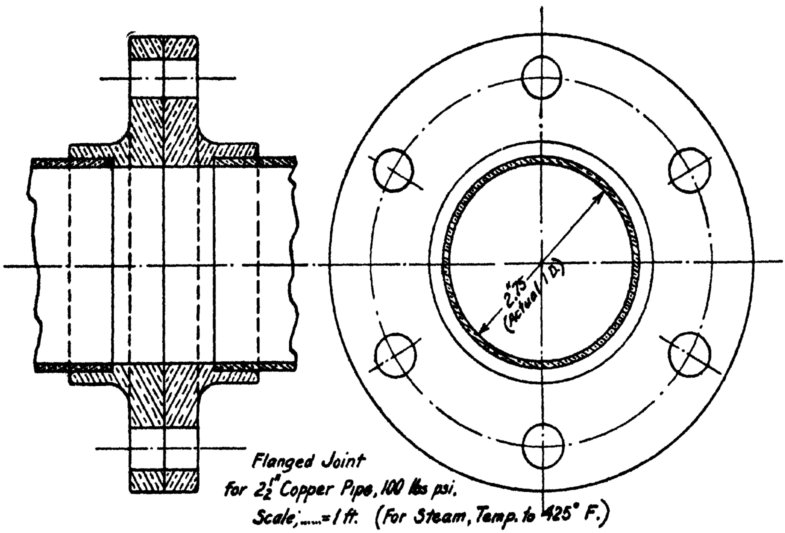


FIG. 116.

dimension appears on this drawing of a 2½" pipe joint the "Actual I.D." is marked, the size conforming to column 9 of page 556.

In use a gasket to fit the service required will be put between the flange faces. This pipe, for steam pressure up to 100 lbs. "psi" (short for "per square inch") at a temperature not to exceed 425° F., may also be used for cold liquids such as fresh water, salt water or fuel oil, up to 150 lbs. psi.

On page 557 are tabulated the dimensions of a set of heavier composition flanges for steam pressures from 101 to 200, and 300

lbs. according to size, and temperatures of 650° F. With cold liquids the pressure may reach 400 lbs.

154. Composition Bulkhead Flanges, with and without Heat and Electric Insulation.—When a pipe line pierces a water-tight bulkhead a special flange called a bulkhead flange replaces one of a pair of plain flanges. It is a flange extended by a thinner, larger flange designed for a second row of bolts by which to bolt it to the bulkhead.

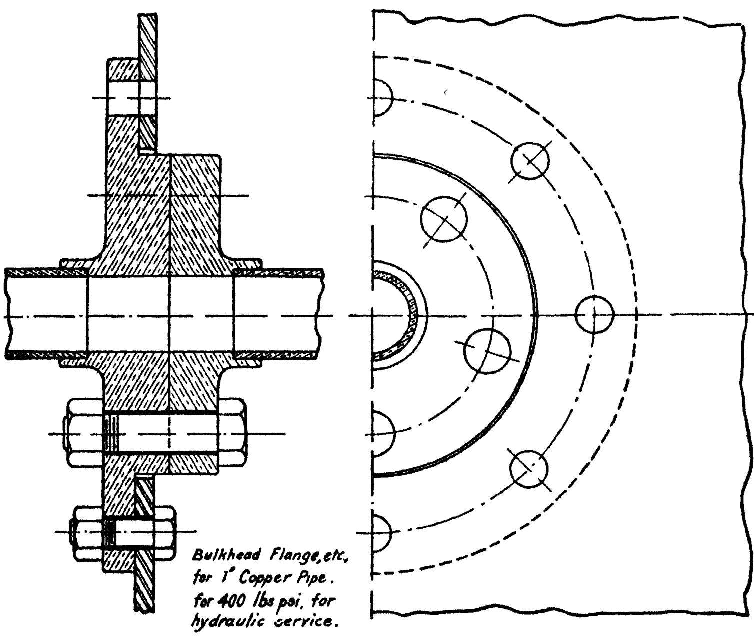


FIG. 117.

In Fig. 117 the combination of bulkhead flange, plain flange, piece of bulkhead with hole cut in it slightly larger than the diameter of the plain flange, is shown. One of each ring of bolts is shown. In use there must be a gasket between the two flanges and a gasket between the bulkhead flange and the bulkhead. As here shown there is no heat or electric insulation and the pipe must be conducting a cold liquid.

Fig. 117 is an "assembly drawing" and for that reason has no broken lines for concealed edges.

The dimensions of the bulkhead flanges, where they differ from those of the plain flanges, are given in columns 18 to 27 of pages 556 and 557.

The key drawing is on page 557 for both kinds. It shows the bulkhead flange bolted to a piece of bulkhead, but insulated from it by heat-insulating material to keep the heat from the bulkhead and from the bulkhead bolts which are in close contact with the bulkhead.

The bolt holes are enlarged to allow for wrapping the bolts with asbestos packing or for slipping insulating ferrules on them.

The "insulating ring" and the two adjacent "$1/16''$" compressed asbestos fiber gaskets" are annular rings whose outside diameters are the dimension M and inside diameters are equal to $M - 2Q$. They are drilled for bolts, of course. The three together must be water-tight as well as resistant to the conduction of heat.

The "insulating washer," diameter Q', and the compressed asbestos fiber gasket under it are of the usual shape of washers. The grommets under the steel washers under the bolt heads and nuts are to preserve water-tightness.

Heat insulation is necessary for pipes carrying steam, hot feed water or hot fuel oil when the temperature exceeds 150° F. Loss of heat from the fluid means loss of efficiency and also uncomfortable quarters on shipboard.

When the insulation is electrical only, the value of the thickness R is reduced to $1/8''$.

155. Steel Pipes for High Pressure Steam.—The old commercial "iron" pipes of page 552 were standardized long ago. They are made of very soft "low carbon" steel and are not suited for what is now called high pressure steam. Nor are copper pipes suited to high temperatures that go with high pressure steam. Steel and alloy-steel pipes are now used, and on page 558 the thicknesses required for pressures up to 900 lbs. are given in columns 1 to 8.

Steel flanges for these pipes are attached by methods depending on the pressure. Those for steam pressures of 100 to 300 lbs. and maximum temperature of 650° F. may be made of cast or forged steel having the dimensions of columns 9 to 21 on page 558.

The bore of the flange is grooved and beveled and the steel pipe is "expanded" by a "tube expander" which enlarges the pipe end,

forcing the metal into the grooves. The end of the pipe is flared out at an angle of 20° by another rolling tool.

The thicknesses of the bulkhead flanges are tabulated under columns 19, 20 and 21. Column 22 gives references where to find other dimensions, including those for the heat insulation. The drawings show a complete section of a plain flange and the top part of a bulkhead flange.

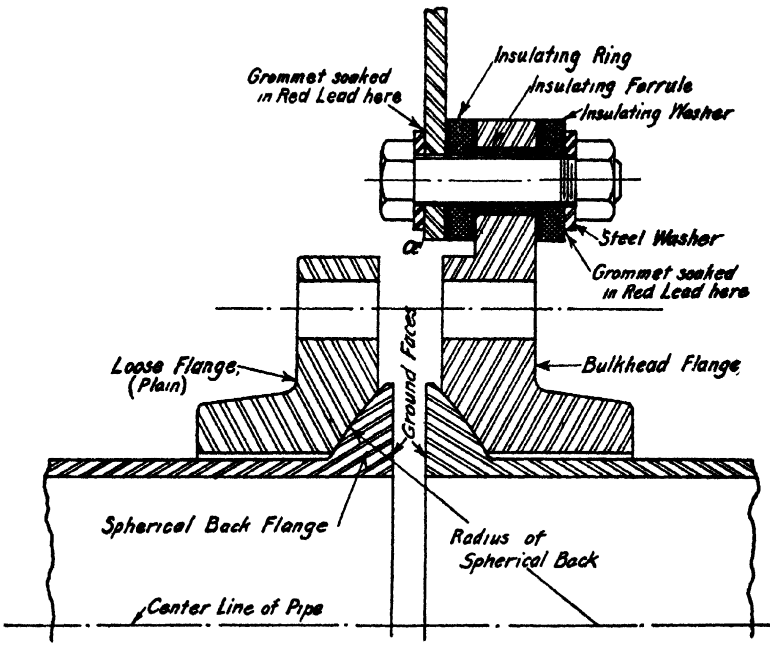


FIG. 118.

Steel fittings cast from the same patterns as the bronze fittings tabulated on page 555, columns 14 to 21, are used with these steel pipes and flanges.

For higher steam pressures there are two series of flanges known as "Spherical Back Van Stone Flanges." One series is for steam pressures to 400 lbs. and 850° F. maximum temperature and for boiler feed service to 600 lbs. with limiting temperature of 425°.

The other series is for steam pressures to 600 lbs. (850°) or boiler feed service to 750 lbs. (425°).

Fig. 118 shows typical plain and bulkhead flanges facing each other ready for bolting. The table of standards is on page 559.

Each pipe end has a loose flange, machined to the dimensions given in the table of standards, slipped over it. The pipe end is heated, upset and forged into a small flange and the spherical back of this flange machined. The flat face is ground to a true plane surface.

The loose flange fits against the special back and can swivel through a small angle like a universal joint. When the bolts are set up the pressure is automatically equalized and the ground faces so perfectly pressed together as to make a steam-tight joint without the use of any gasket whatever.

156. Rules for Drilling Flanges.—The directions for drilling flanges are often put on drawings by a label of this kind, "Drill five $^{11}/_{16}''$ holes for $^5/_8''$ bolts on $4^1/_{16}''$ p.c."

On the drawing of the face of the flange one hole should be located on the pitch circle and the arrow from the label should reach to the specifically located hole. To locate one is to locate all since the spacing is always uniform.

On an elbow or tee we seek always to avoid that point on the pitch circle which is nearest to an adjacent flange. Difficulty in getting the bolt in place or in screwing up the nut is the reason for this rule. The spot to be avoided will fall between two holes if the first bolt hole is located as follows:

If the number of bolts is odd begin opposite to the spot to be avoided.

If the number is divisible by 2 but not by 4 begin at 90° from the spot to be avoided.

If there are 4, 12 or 20 bolts begin at 45° from that spot. If there are 8 or 16 begin at angles of $22\frac{1}{2}$°, or $11\frac{1}{4}$°, respectively.

Problems

42. How are pipes named and thickness regulated? What is the standard taper for an **NPT** thread? What is meant by a nozzle? What is a boss on a pipe flange?

43. When should bolt holes drawn on the face view of a flange be projected to the side view? (p. 409.) What spot is avoided in locating bolts on the flange of an ell? How avoid it if the number of bolts is even but not divisible by four?

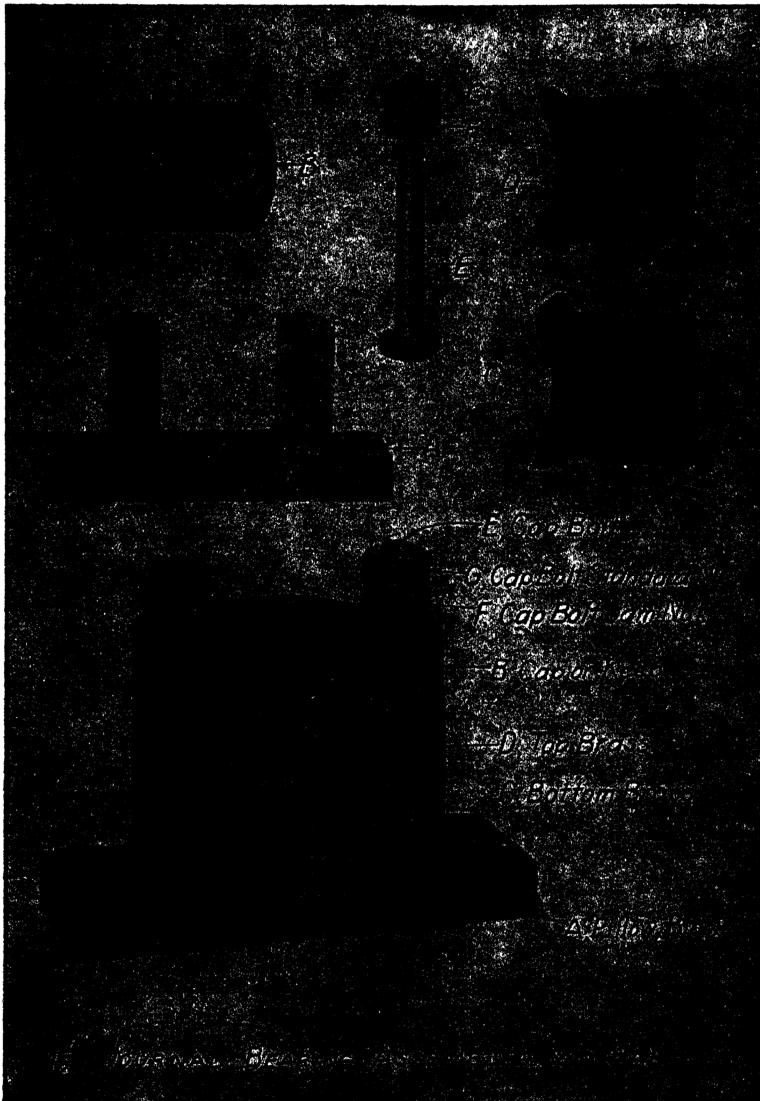


FIG. 119.
(Fig. 31, Repeated.)

CHAPTER IX

DETAIL DRAWINGS

157. Detail and Assembly Drawings Contrasted.—On the opposite page, a former page (415), a "halftone" prepared from photographs of a Journal Bearing, is reprinted.

The top half shows each part photographed separately and is therefore a *Photographic Sheet of Details.* The bottom half shows the assembled bearing. It is a *Photographic Assembly.* Neither of these halves could have been produced in advance of manufacturing at least one complete bearing. They are meant for instruction only, not for manufacture.

We wish now to consider mechanical drawing as an indispensable step towards the manufacture of mechanical devices. Complete sets of drawings precede the manufacture of practically all machines today.

For a new machine the process is about as follows: Some inventive person imagines something different or better or cheaper than existing devices and he makes a sketch of the assembled device.

After it has been discussed, changed and improved, by himself or by others, a formal drawing is begun. The engineers concerned begin to plan the separate parts and to make drawings of the details, keeping in mind easy and cheap ways to manufacture them, as well as the proper functioning of each part.

Soon an assembly drawing and a sheet of details are evolved, the assembly always a bit ahead of the details, since many details can be left in the rough awaiting the final judgment of the designing force.

The assembly serves for estimating the suitability of the design as part of a larger mechanism, for comparing it with existing similar mechanisms and for estimating how it can be repaired and serviced in use.

The sheet of Detail Drawings is the form in which the design

leaves the draftsmen and engineers and goes into the shops for actual manufacture. It is a collection of drawings of separate pieces belonging to the same mechanism, correct in scale and fully dimensioned. It is a sheet of "small machine parts" with one added requirement.

The new feature to be kept in mind is the interrelation of the parts. One part exactly fits another or fits with definite clearance within definite limits. Dimensions must be in accord or a lack of fit will appear when the attempt is made to assemble the parts. For instruction purposes we consider the details before the assembly.

158. Separation into Parts.—Each part has its separate drawing. A part is usually a single piece of metal, separately manufactured, but two parts riveted together may be shown in one, and parts manufactured in pairs, like *C* and *D* of the bearing are often shown together. A bearing with white metal poured in place, and machined in one with it, is considered one piece as regards manufacture. As an exception, nuts are often drawn on their threads. Standard nuts need not be drawn at all if listed in the bill of materials. Plate III, the parts of a 1″ throttle valve, by which the engineer controls the steam flowing to a steam winch or other small engine, is a typical sheet of details. It faces page 533.

159. Standardized Parts.—Simple parts are listed but not drawn. Many, like bolts, are shown with key dimensions only, all minor dimensions being assumed to be standard.

160. Grouping of Parts.—Here three desires conflict. (1) There is a distinct desire to group the parts manufactured in the same shop together; all the castings together, all the steel forgings together. (2) There is a desire to group them in such a way as to suggest assembly. Note page 440. Partial assemblies in diagrammatic form are used. The suggestion of assembly makes it easy to check dimensions which must me alike on "faying" or touching pieces. (3) The desire to get the details into compact form on the size of sheet in use at the manufacturing plant in question causes some shifting of views. This adjusting to size of sheet is called "blocking out."

161. Selection of Views and Scales.—Consider each piece as we have done before. When blocking out, adjust scales, resort to half views, or shift from a right side view to a left one, if it will better

fit a vacancy on the sheet or suggest assembly well. One must never spoil the clarity of the individual drawing by using poorly chosen views simply for the sake of a suggested assembly. That is always a secondary matter. Absolutely definite and clear information as to manufacture of each piece is the fundamental requirement.

162. Bill of Materials.—We have mentioned the bill of materials as a tabulation of information needed in manufacture. A good form is shown just below. The names of the pieces, the distinctive mark (letter or number), the number required and the material are always recorded. The bill itself is put close to the legend, just above or to the left. On our sheets hereafter when bills of material are proper we expect to record them as a matter of good practice.

For the Journal Bearing the bill of materials reads:

Name of Piece	Mark	Number Required	Material
Pillow Block	A	1	Cast Iron
Cap or Keep	B	1	Cast Steel
Bottom Journal Brass	C	1	Composition
Top Journal Brass	D	1	Composition
Cap Bolts	E	2	Forged Steel
Cap Bolt Jam Nuts	F	2	Forged Steel
Cap Bolt Standard Nuts	G	2	Forged Steel

163. Schedule of Alterations.—Nearly every design is faulty when first put out. Improvements are discovered and the manufacture changed to conform. Great improvements cause the entire mechanism to get a new number or name. "Mark 5," etc., for types of guns. J-3, J-4, J-5, J-6 for the successive improvements on a well-known aviation engine. These major improvements require full new sets of drawings, both detail and assembly. Not so radical, however, are many small alterations, which perhaps are never put on the assembly (since the assembly omits many details), but must be put on the detail drawings used in the shops as soon as possible.

Each change is recorded in a schedule of alterations which, like the bill of materials, gets as close to the legend as space permits.

The schedule lists the alterations, giving each one a distinctive letter or mark, the date adopted and the pieces affected by it. The drawing of the pieces is then corrected or it is crossed out and a new one made with a notation such as "See alteration A."

164. Detail Drawings from Mechanisms.—Some detail drawings, particularly those made by students following courses of instruction, are made from actual mechanical assemblies such as the 1½″ Journal Bearing, page 516, or the 3″ Globe Valve, page 417.

A model is issued to a group of students who disassemble it, divide up the parts, and proceed to make a set of detail sketches, passing the parts around until each student has a complete set of sketches.

The model is reassembled and removed and the students make the detail drawings *from their sketches.* If the sketches are complete the work progresses unhaltingly. The student must omit no important measurement when sketching. Errors which may not show on the sheet of details will be sure to give trouble if an assembly is made from the same data.

165. Detail Drawings from Assembly Drawings.—A common educational device and a common procedure in drafting rooms in general is the making of details from assembly drawings. Work is started directly from the blueprint or other print furnished, without preliminary sketches. The first task is to "read the drawing." Spend a reasonable amount of time first, verifying all parts by name and letter and studying all the labels and the bill of materials as well as all the views and sections. Consider the fastenings and the joints by which it comes apart. In fact, mentally disassemble it before beginning the detail drawings.

Problems

44. Give the rule for separation into parts in making detail drawings. When is special grouping desirable? What items go on the bill of materials? When can one drawing do for two pieces?

45. What is the special purpose of the sheet of detail drawings?

46. What particular purposes are served by the assembly drawing?

CHAPTER X

ASSEMBLY DRAWING

166. Purposes of the Assembly Drawing.—These have been well covered by Art. 157, page 517, when considered as part of the manufacturing process, especially necessary for new devices and constructions.

Young engineers, however, will be thinking not so much of possible new developments as of getting acquainted with existing machines. For this purpose the Assembly Drawing is preeminent. When in the future you are given charge of any machinery to operate, ask at once for the "layout" and the assembly drawings of the various parts. Read these blueprints and check them on the spot with the actual machinery as soon as time permits.

The assembly is much used in courses of instruction. To make the details from an assembly requires the student to read the assembly to the last line, an invaluable lesson.

Moreover, after completing the drawing course any student of engineering will find that all his textbooks use assemblies, often in much simplified and abbreviated form, to teach what the student must learn about the forms of the machines of today.

167. Simple Assemblies May Be "Complete."—Assemblies of very simple things are sometimes so complete, so fortified with detail dimensions and instructions in the form of labels, that they may serve a double purpose, as both detail and assembly drawing. This is rare and, as a rule, one must not expect the assembly to serve for actual manufacture.

168. Assemblies Usually Incomplete and Abbreviated.—To make an assembly easily understandable it is usually necessary to leave parts of the mechanism incompletely drawn, to have parts designed along well-known lines shown by suggestion, and to reduce the actual theoretically necessary lines to a minimum. Parts having small clearances, for instance, are shown as if in contact, one line

serving for two. The question of clearances and tolerances is one for the detail sheet only.

As far as possible broken lines for concealed edges are reduced to a minimum. The true cross section with no lines for parts back of the plane of section may replace the sectional view. Thus in Fig. 118, page 514, there are no broken lines and some full lines, theoretically necessary, are ignored. Corner *a* marks the place where a full line in theory should be drawn all the way down to the H.C.L.

The assembly will be to scale, of course, but very few dimensions will be recorded. The proper dimensions are discussed in Art. 174.

169. Assemblies for Educational Purposes.—All assemblies are in a sense educational, but for formal instruction in drawing courses assemblies are partly completed, dimensions added to some degree, labels added to explain details. The aim is to make the student by degrees a "detail designer." Reading such assemblies and proving his understanding by making detail drawings of some vital parts is a fine educational process.

170. Assemblies for Higher Studies in Engineering.—Assemblies for textbook uses are usually much abbreviated. In them one view only is common. It is prepared on the assumption that the student already knows something about the machine or its like and does not need complete information to see how it operates.

Usually the view or section chosen to present the idea vividly is shaded to give some idea of depth and to guide the imagination into the right channel. Such assemblies you will see later.

171. How to Assemble the Parts of an Actual Mechanism.—The parts of a machine, given to a person unfamiliar with their use but eager to learn, are a challenge to his mind, and often give a useful lesson.

One instinctively begins to look for matching dimensions. One part is tested to see if it can be inserted in another without too loose a fit. If the fit is tight we think no motion is intended. If it is an easy fit motion may be intended. If we see a screw thread we try to find a nut or a tapped hole into which it can screw. We try to identify well-known features of design and argue the purpose from them. A gasket or a stuffing box suggests pressure difference and fluid flow, etc.

172. Assemblies To Be Made from Detail Drawings.—For educational purposes this is a natural companion process to the making of details from assemblies. If a detail drawing is issued the student must make from it an assembly. He thereby learns the value of each line of an assembly. Many simple assemblies are made from isometric details, such as those of page 440.

173. Mental Assembly of Details.—Before trying to make an assembly from a given sheet of details put some time first to making a mental assembly. It may save time in the long run.

The mental process closely parallels the handling of the actual parts. Search the detail drawings for similar shapes and dimensions, particularly center to center distances. Mentally fit part to part. If unable to begin, study the bill of materials. The names suggest the functions. Parts similarly named are likely to be in contact. Thus a "gland" and a "gland stud bolt" suggest assembly together. When the number of bolt holes and the number of stud bolts agree a strong presumption of fit is indicated. A "ground face" recorded on one piece makes one search for another ground face, for the fit of a ground face against an ordinary machined surface lacks purpose.

Threads whose number per inch are recorded are apt to be unusual threads and invite search for the matching thread elsewhere.

174. Dimensions Which Should Be Recorded on the Assembly.—The assembly is often a detail of some larger group of machines in a layout. All the dimensions which record the fit with other elements of the layout, or which show the fastening to the foundation, are necessary. Overall dimensions are desirable because they give the space necessary to allow for installation and accessibility for repairs. A few main dimensions may be allowed to give the impression of size for comparison with other similar installations.

175. Views and Lines Needed on the Assembly Drawing.—The views of an assembled mechanism will often accord with those of the largest piece or "body" on the detail sheet. The usual "considerations" of Arts. 75-77, pages 446-448, govern the proper selection of views of the whole as of the parts but in the assembled position many a small part must necessarily be in a different position from the one naturally chosen for that piece if drawn alone.

Mechanisms usually have a complete cycle of movements and when at rest may be put in any one of an infinite number of positions. For the assembly drawing the draftsman chooses that position which puts as many important parts of the mechanism as possible in natural positions, not oblique. Obviously, however, some parts may have to be sacrificed and put in oblique positions for the good of the others. See Art. 127, page 355.

In Art. 168, page 521, reasons for the omission of many broken lines and some full lines were given.

In actually drawing a view of a machine, as assembled, try to draw from the near to the distant. If the object is considered as lying on the drawing paper, then the statement may well be "draw from the top down." Bottom parts may fall entirely behind or under the nearer parts already drawn. This makes it easy to decide what parts of lines are broken instead of full, and it helps to show what dotted or broken lines are unnecessary and therefore rightfully omitted.

CHAPTER XI

SET OF ENGINEERING DRAWINGS

176. Drawing Sheets Are Varied from Year to Year.—It is impossible and undesirable to confine the drawing sheets which put into practice the teachings of Part III to any rigid set. New material is constantly coming up and being put into use. We can only recommend an order of progression based on the chapters, and indicate the kinds of sheets desirable. Directions can be given in some cases when the sheets are based on material in this textbook.

177. Sheets Based on Chapters I to V.—It is supposed that a number of small machine parts, such as those of pages 450 and 451, or any other simple objects, have been sketched. To test the completeness of the information recorded on the sketches some should be selected to be drawn on a sheet of standard size, laid out as on page 110. Two, or possibly three, subjects make a good sheet.

At this point the student first meets the rather puzzling task of himself selecting scales, arrangement of views and positions on the sheet so adjusted as to use the paper to the best advantage. In other words he has to **block out** the sheet. We can give several points to observe. (1) Use no scale not on the triangular scale, except half size or double size. (2) When it is difficult to get a scale large enough to make the drawing easy to make and easy to read, see if the use of half views will help. (3) If the L-shaped group of views most often seen is not the right shape to fit the place in the paper left for it, see if a shift from a right to a left-side view, or a right-side view abreast the plan, will help. (4) If a piece is long a break-out of a middle section may help.

Within limits, the larger the scale the easier the drawing is to make.

178. Scale Sketches from Freehand Sketches.—A second sheet based on Chapter V may well follow the first one, and, as a change it may be a sheet of scale sketches, such as are described in Art. 52, page 423. Use a softer lead than usual and use instruments or draw free hand, *whichever is quickest for the particular line in question.* There is an accurate and inexpensive paper, ruled in inches and eighths in blue ink, outside size 16″ × 21″, field 15″ × 20″.

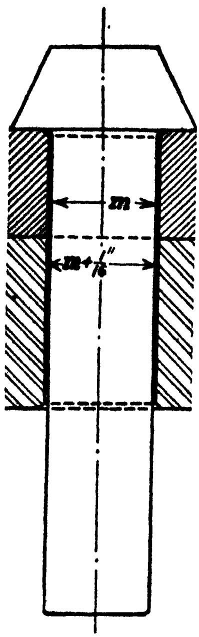


FIG. 120.

179. Sheets Based on Chapters VI and VII.—Figs. 106 to 109 on page 500 were reduced approximately to half size in printing. Arranged as they are, they make a good drawing sheet when drawn full size with the dimensions shown as letters converted into inches. For example, as follows: $a = 2\frac{1}{2}''$, $b = 1''$, $c = \frac{7}{8}''$, $d = 3\frac{7}{8}''$ and $e = 2''$. The two ordnance screws are to be drawn half size with $f = 1\frac{3}{4}''$ and $g = 1\frac{1}{2}''$. The detail dimensions are taken of course from page 547 and Art. 137, page 495. Sketches should precede the drawing.

180. Sheet of Fastenings Based on Chapters VI and VII.—Figs. 110 to 112 on page 501 make an instructive sheet if drawn full size with dimensions converted as follows: $h = 1\frac{3}{4}''$, $i = 2''$, $j = 1\frac{3}{4}''$, $k = 2\frac{3}{4}''$, $l = 1\frac{3}{4}''$, $n = 1\frac{1}{4}''$, $o = 1\frac{5}{8}''$, $p = \frac{1}{4}''$ and $r = 1\frac{1}{8}''$. Detail dimensions are taken from pages 547 and 548. Large sketches should be made and detail dimensions recorded on them before starting the drawing.

The two plates may be extended to the left to make room for a bore hole of $1\frac{1}{4}''$, with $\frac{1}{8}''$ 45° bevels in which can be drawn a $1\frac{3}{16}''$ boiler rivet shown before closing, as in Fig. 120. Detail dimensions are obtained from pages 550 and 551.

181. Sheets Based on Chapter VIII.—The pipe fittings shown in Figs. 121 and 122 here may be drawn to a large scale, taking the detail dimensions from pages 554 and 555. Let the T be of cast

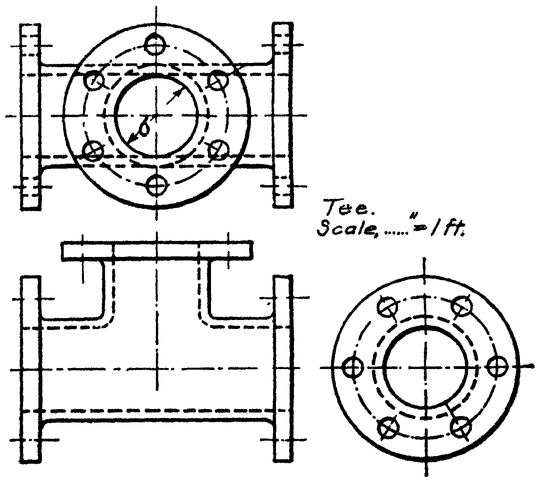
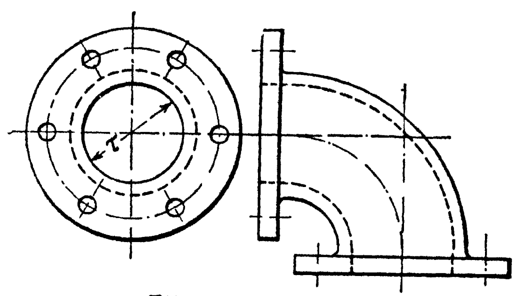


FIG. 121.



Ell or Elbow.
Scale, ..." = 1 ft.

FIG. 122.

iron for 100 lbs. pressure and 3″ size. Let the ell be of composition for 100 lbs. pressure and 5″ size. Put the proper number of bolt holes, not six, in each flange and follow the rules given in Art. 156 of page 515.

The standard three-part Screw Pipe Union of page 553 may be drawn full size, a plan, a front-view-in-section and a side view, using a large example, say $2\frac{1}{2}$″.

182. Flanges for Copper Pipes.—Based on Chapter VIII, a sheet

of composition Flanges for Copper Pipes can be drawn from the tabulated dimensions of pages 556 and 557. The aim is to produce such a drawing as Fig. 116, page 511. The suggested size is $2\frac{1}{2}''$ and pressure 300 lbs.

183. Bulkhead Flange for Copper Pipe.—Based on Chapter VIII, a more complicated drawing is that of a bulkhead flange, for Copper Pipe, a piece of bulkhead, a standard flange and the bolts, like Fig. 117, page 512. Take the data from pages 556 and 557 for a $1\frac{1}{2}''$ size, pressure of 100 lbs. for hydraulic service, without heat insulation.

184. Drawings Based on Chapter IX.—The first detail sheet may well be one based on the $1\frac{1}{2}''$ Journal Bearing shown on page 516. In that case a model is issued to a group of students who disassemble it and sketch and measure each piece in turn. It is important to get all the measurements needed to draw the pieces. To check the completeness of your dimensions imagine yourself plotting the points which locate the lines from the center lines or base lines in the manner described in Art. 125, page 352.

The Bill of Materials (repeated from page 519) reads:

Name of Piece	Mark	Number Required	Material
Pillow Block....................	A	1	Cast Iron
Cap or Keep..................	B	1	Cast Steel
Bottom Journal Brass............	C	1	Composition
Top Journal Brass...............	D	1	Composition
Cap Bolts.......................	E	2	Forged Steel
Cap Bolt Jam Nuts..............	F	2	Forged Steel
Cap Bolt Standard Nuts.........	G	2	Forged Steel

The student should note the following points about the various parts.

185. The Pillow Block, Piece A.—The piece is evidently a casting and some of the original surface remains. It is not "finished all over." There are two surfaces which seem to be parts of a large cylinder. Careful measurement by the outside calipers betrays the fact that it tapers slightly. We recognize this taper as the "draft" given by the patternmaker to the pattern so that when

removed from the sand the pattern will quickly clear itself from the sand with little danger of breaking the impression. We do not draw this taper but convert the drawing to the representation of a cylinder. Draft is always left to the patternmaker and molder. A change in method of casting may cause them to change one draft to another. Note the spotfaces. Note a square cored recess and the drilled bolt holes. When we sketch and draw, each surface to be finished should be marked, on that view in which it appears on edge, by a standard finish mark and reference letter as shown at the bottom of page 543.

186. Cap or Keep, Piece B.—This also is a casting. In a big bearing it should be of cast steel, not cast iron, since considerable tensile stresses will be experienced by it. We will assume it to be of cast steel. The rounded ends are parts of the same large cylinder. It is thickened at the middle by a spherical swelling. We cannot measure the radius of the sphere directly but we see that we can deduce it from careful measurements of the line of intersection with the side surface. This gives an arc of circle like one on Fig. 70, page 457, where *fed* is measured by measuring the distance *fe* and the rise of arc *y*. These measurements will be required on the sketch. Later on we will arrive at the radius of the sphere and discard the temporary measures.

The bolt holes have been drilled and a recess cut into the spherical bulge so that the nuts may turn. Also there is a counterbore to surface noted.

The tapped hole in the middle is for a $\frac{1}{8}''$ pipe. We need only mark it "Drill and tap for $\frac{1}{8}''$ **NPT**, $\frac{3}{8}''$ deep." In use a grease cup will probably be screwed into it. The small hole at bottom is a $\frac{1}{8}''$ oil hole. When drawing it avoid sectioning. Follow 23, p. 546.

187. Top and Bottom Brasses, C and D.—**C** and **D** differ only in that on **C** the corners of the prismatic body are beveled off, and on **D** we have an oil hole, $\frac{1}{8}''$, and an oil groove, $\frac{1}{8}''$ wide and $\frac{1}{16}''$ deep, nearly from side to side. Both are machined all over, and are brass or bronze castings, not forgings.

Three ways to sketch and draw are permissible. Each may be described alone. One sketch may serve for both by adding labels in regard to the variations shown. Thus the oil hole and channel

may be marked, "Drill and groove **D** only." The corners may be shown beveled with a note, "Leave corners square on **D**." The two may be drawn together, in position, as assembled or pulled apart an inch or so. The group may consist of a plan, front and side view for **D**, and a front, side and bottom view for **C**, each being drawn in natural position as regards gravity. (Consideration **c**.)

188. Cap Bolt, E, and Nuts, F and G.—However rough this bolt may be found to be, draw it as a standard bolt, following p. 547. Do not be concerned if the nuts are chamfered differently from those shown in the tables. The jam nut should properly go on the bolt first, though many mechanics have a wrong idea about this. **F** and **G** may be drawn on the bolt **E**, or drawn separately or merely tabulated in the bill of materials.

189. Details of 3″ Navy Valve.—A 3″ globe or angle valve, like that on page 417 (or 418), may be issued to a group of students to be immediately broken down and the parts divided for sketching and measuring.

This is the bill of materials:

Name of Piece	Mark	Number Required	Material
Valve Body	A	1	Composition
Bonnet	B	1	"
Valve Disc	C	1	"
Valve Nut, Special	D	1	"
Valve Spindle	E	1	Rolled Bronze
Valve Spindle Nut	F	1	Composition
Hand Wheel	G	1	"
Stuffing-box Gland	H	1	"
Stuffing-box Stud Bolts	I	2	"
Stuffing-box Stud Bolt Nuts	J	2	"
Yoke	K	1	Wrought Steel
Yoke Columns	L	2	"
Yoke Column Nuts	M	2	"
Bonnet Stud Bolts	N	8	"
Bonnet Stud Bolt Nuts	O	8	Composition
Pin	P	1	"

The actual valve body, **A**, is very complex and a print of it, fully dimensioned, is often issued as a time-saving device.

Neither nut **D** nor pin **P** will be found in the angle valve of page 418.

The rolled bronze valve spindle is of a special composition and it has been hot-rolled; this has made it nearly as strong as ordinary steel.

The choice of views for each piece, the sections and the dimensions must all be determined on general principles. A few special points should be mentioned about the valve parts.

The *globe valve* was so named because older designs were based on a hollow sphere. This one is based on a hollow double ogival point intersected by a cone, for which see Sheet 16, Part II, p. 377. Another name for this valve is a "straight-way valve" because the fluid travels on in the same line after passing through the valve.

The *angle valve* is named from the change in direction of 90°, in the flow of the fluid. Curiously enough its form is here actually based on a globe or sphere.

The valve bonnet, **B**, is largely a surface of revolution.

The valve spindle, **F**, has an Acme thread. See columns 18 and 19 of page 547. Note whether it is the standard Acme thread or not. Record the number of threads per inch in either case.

The valve disc **C** (or **C′**) has a ground conical valve face to match the hollow ground conical valve seat on the body. Underneath the valve disc are three ribs which serve to guide its motion. The attachment of the valve disc to the valve spindle is purposely a loose one, so that the valve can seat itself properly despite distortion from heat or bad workmanship.

The disc **C′** has a smooth bore hole, but **C**, shown at the bottom of page 418, has a special hollow thread into which the outside thread on valve nut **D** screws. This is a typical sharp V-thread, cut on the lathe, mentioned in Art. 138, page 496.

190. Detail Drawings from Assembly Drawings.—Many detail drawings are made from assembly drawings, both in school and in general practice. This has been fully explained.

If, in your course of instruction, old drawings are issued some older methods of drawing will be observed, older than those which

are now standard. No such obsolete features should be retained in making details from such drawings. Replace the old methods by the new. In the future you will handle many old drawings. Do not let them influence your methods of drawing however.

191. Assembly Drawings Based on Chapter X.—The first assembly drawing may well be the assembly of the $1\frac{1}{2}''$ Journal Bearing of page 516, especially if the details of that bearing have already been drawn, as described in Arts. 184 to 189, pages 528 and 529. The bearing as a whole is subject to the same considerations as are single pieces. **a**, **b**, **c**, **d** and **g** of pages 447 and 448 all apply.

To show up the beveled corners of the bottom brass and the square recess for the heads of the $\frac{1}{2}''$ bolts, a partial section should be shown on the front view. A break-out like Fig. 6, page 397, may be so chosen as to take in the details it is desired to emphasize.

In general, when drawing an assembly, the advisability of omitting lines for concealed edges arises. Each view is considered by itself. The lines to be omitted first are those farthest from the eye. If the omission begins to leave the drawing seriously incomplete the draftsman casts about for half sections and the like to show the interior.

192. Assembly of the 3″ Navy Valve.—This assembly may be made, of course, from sketches made by the individual student from the actual parts of a valve. Time, however, rarely permits this.

More often a sheet of details is issued and, in addition, a sheet of drawing paper with the body of the valve partly printed on it so that the assembly can proceed rapidly by adding the smaller parts to it.

Of course some helpful information may be derived from Art. 189, page 530.

193. Assembly of the 1″ Throttle Valve from the Sheet of Details.—Facing this page is Plate III, showing the details of a valve by which the operator of a small steam engine for a steam winch can control the speed and power of the engine instantly.

A special size of paper may be issued for this sheet with directions for the location of center lines, etc. It is usual to assemble the parts on the body, and, depending on the time available, a plan and a section-on-the-front-view, with or without the side view, may be drawn.

Study the sheet of details and make your mental assembly first. Time so spent is not wasted.

First draw enough of the front-view-in-section of the body, **A**, to locate the flange *ef* and parts above. Then draw *M* on the flange, *ef,* and locate the H.C.L. of the curved slot. On this line place the lever **K**, turned end for end, from the position on Plate III.

We are now ready to work in a systematic way, finishing three views of each piece as we come to it, and the order to be taken is *from the top down.* Finish the top of the slot of *M* first in all three views. Then concentrate on the lever **K** and parts **P**, **Q** and **C**. None of these is to be sectioned. Drawing in this order one realizes, from the start, what parts of each piece are concealed under other parts, above them, which have already been drawn. It becomes easy to decide on broken lines and easy, too, to decide when to omit broken lines for the sake of clarity.

The next parts to be drawn will be **L** and **J**, and the two pins, **O**. **L** is not quite vertical. Its C.L. inclines $\frac{1}{16}''$ from the vertical. Finish piece **M** now, also, and insert pin **N**.

We are now in the region of the stuffing box and pieces **E** and **D** are drawn, in full-section, on the front view. **E** may be anywhere on its thread from a mere half turn to hard down, according to the packing. We will draw it halfway down, say. We must now represent the thread of pitch $\frac{1}{12}''$. Use Fig. 6 of p. 546 on the side view, and Fig. 22 on the front view, intending to keep hatching lines away from the small V's as shown. There is no taper to these threads, and the pitch is left to the eye. Freehand work is quite acceptable here, and in fact the threads of Fig. 22 of p. 546 were made freehand.

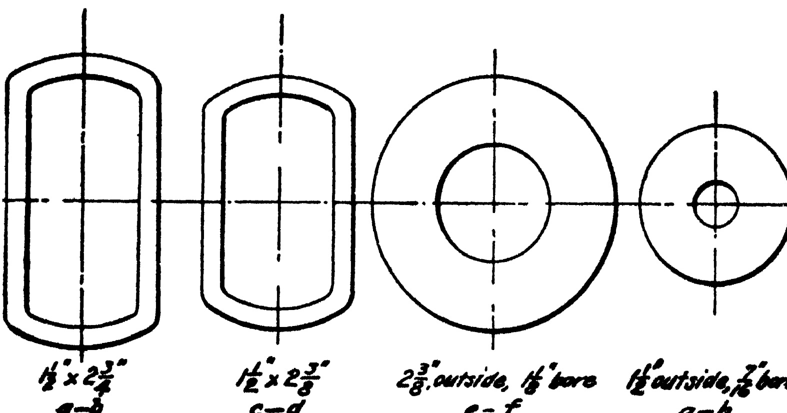


FIG. 123. FIG. 124. FIG. 125. FIG. 126.

The gland **D** is, of course, under **E** but as far up as it can go. The *stuffing space is empty,* as is the rule for valve drawings, usually followed.

From this point on it is necessary to omit many lines from the plan and some from the side view. In general, **omit broken lines when their presence would unduly complicate an assembly drawing.**

Nut **F** is now drawn. Its hexagon is large so that it may be turned by a thick wrench without turning **E**.

The valve body, **A**, has a complicated geometrical shape. **Figs. 123 to 126 are various cross sections, at *a-b, c-d, e-f* and *g-h*.**

The true valve is the piece, **H**, and the valve seat is the piece, **G**, the ground faces sliding on each other. Steam pressure entering the left nozzle of **A**, when the nozzle of **G** is connected to a pipe of lower pressure, will blow **H** against **G**. We are drawing the valve in a half open position. Lower **H** and it will completely block **G**, the ground surfaces being steam tight. This valve is a lever-operated "gate valve," for quick action in controlling a steam engine. Strap, **B**, partly spherical, holds **H** loosely in place.

The gasket between **A** and **G** is a ring of $2\frac{3}{4}''$ with a $2\frac{1}{4}''$ hole, of a thickness dependent on the packing material for the service intended. Draw it squeezed into the $\frac{1}{16}''$ packing grooves, yet keeping the face of **G** $\frac{3}{32}''$ away from the face of **A**. Hatch the gasket where sectioned solid black like No. 12 on p. 545.

Vary the angle of hatching for each piece. See Art. 15. In pencilling "indicate" hatching, in small corners only.

Now that the valve is assembled we can see how it operates. The lever mechanism is what is known as a "parallel motion linkage," which is in reality a device for guiding a point in a straight line, in this case for guiding the top of the valve stem in a straight line. This device depends on a mathematical relation between the distances from hole to hole of the lever, and the radius of the slot. "Parallel motion" is an old term for a device for guiding a point in a straight line by levers only. One point of the lever **K**, that to the left, is $3''$ and $5''$ from the others. The radius of the slot is $8\frac{3}{8}''$. The relationship is this: $3'' \times 8\frac{3}{8}'' = (5'')^2$. The reason is treated in the subject of mechanism, where the subject of the "grasshopper engine parallel motion" is treated. In this case the device serves to guide the top of the valve stem in a straight line.

Show, by center lines only, the position of the lever for full open and full shut positions, and verify that the eye of **J** is still on the V.C.L.

194. Assembly Drawing from Isometric Detail Drawings.—Many subjects of this kind are available. On page 440 the "Hooke's Joint" shown is a sheet of isometric details arranged for making an orthographic assembly of two views. This is shown by the isometric axes, two of which, marked with arrows, give the directions for viewing the assembly for the two views expected, a "side elevation" and "front elevation."

195. Assembly Drawing of Monkey Wrench from Plate IV.—Plate IV, which faces this page, has all the directions for making the assembly. The subject is a little more difficult than it seems at first sight. Students do not at first see the reason for a $\frac{1}{8}''$ notch in the $\frac{1}{4}'' \times \frac{7}{8}''$ shank which slips into the handle **E** to give it strength. It is needed for the assembly of the pieces **B, C** and **D**, and after **D** is riveted to the shank of **A** the wrench cannot be disassembled accidentally even when opened to its fullest extent. Check this feature when the assembly has been made.

TABLES OF STANDARDS

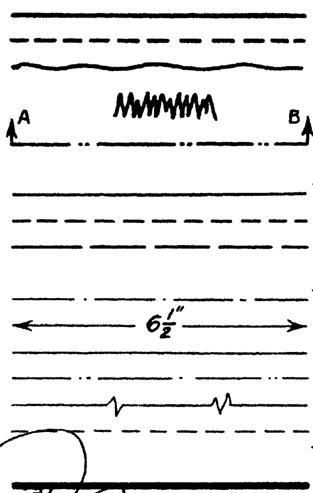
CHIEFLY

STANDARDS ADOPTED BY THE BUREAUS OF THE
U. S. NAVY DEPARTMENT

CONTENTS OF TABLES OF STANDARDS

Note 1. American Standard of Drawing and Drafting Room Practice, 1935.
Note 2. National Screw Thread Commission, 1929.
Note 3. Long Established Commercial Standards.
Note 4. U. S. Navy Standards, as in force December, 1940.

STANDARD LINES



"Standard" or "Heavy" Lines, 0."015 thick.

1. Visible Edge or Outline.
2. Invisible Edge.
3. Short Break (metal, etc.).
4. Short Break (fibrous material, wood, etc.).
5. Path of Section (when not along a center line).

"Medium" Lines, 0."01 thick

6. Visible Edges in crowded area.
7. Invisible Edges, crowded area.
8. Position after movement, or adjacent parts.

"Imaginary" or "Fine" Lines, 0."005 thick.

9. Center Line.
10. Dimension Line.
11. Axes, Traces, Hatching.
12. Construction Line.
13. Long Break.
14. Line of motion, Hatching.

0."025 15. Shade Line. "Extra Heavy".

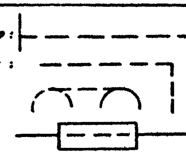
MODIFIED LINES FOR RAPID WORK IN PENCIL

No. 2 – Double length dashes

No. 10 – Gaps to distinguish from No. 1:

No. 12 – Faint, continuous, if not to be inked

PROPER USE OF BROKEN LINES FOR INVISIBLE EDGES, – LINE No. 2 –



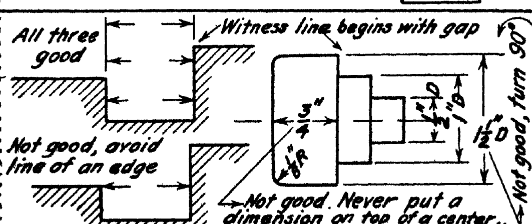
End on a full line with dash not gap:

Two meet at a corner with dashes:

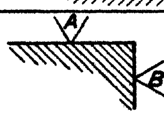
Meet tangent arcs with dashes:

Full line becomes hidden at a gap:

PROPER USE OF DIMENSION LINES AND EXTENSION, OR WITNESS, LINES, – LINE No. 10 –



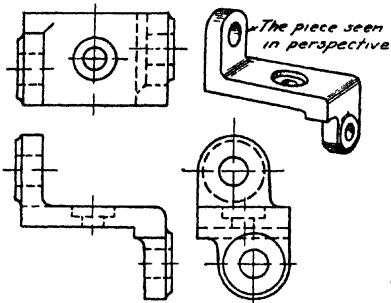
STANDARD FINISH MARKS (Replacing mark f)



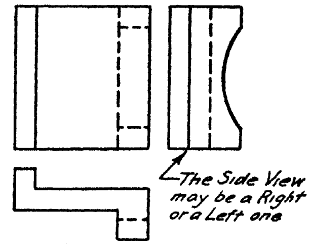
Use two short 60° lines with a reference or code letter which should be explained on the drawing by some note.

(See pages 36, 397, 401–403)

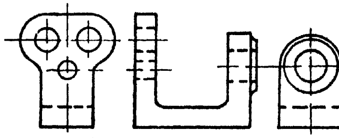
STANDARD VIEWS & SECTIONS.



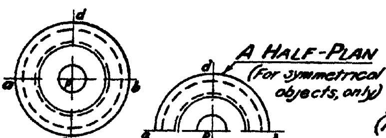
THIS IS THE USUAL GROUP OF 3 VIEWS.
(A plan, front view and right, or left, side view)

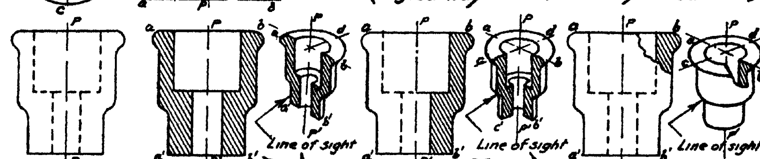


ANOTHER COMMON GROUP OF 3 VIEWS
(When the plan is large in area this makes a compact drawing)



ANOTHER GROUP, A VIEW & 2 PART-VIEWS
(A good way to avoid too many dotted lines)



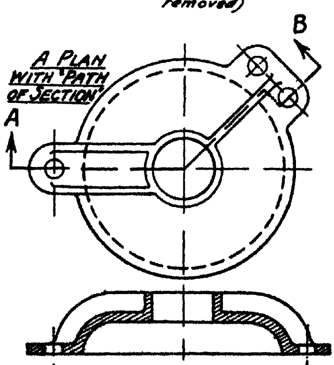


2 VIEWS ONLY
(For surfaces of Revolution, etc.)

THE SECTION
(Or "full-section", With half of object removed)

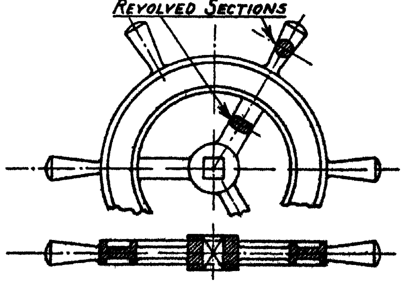
THE HALF-SECTION
(With one quarter of the object removed)

THE PARTIAL SECTION
(With only a small fraction of the object broken off)



"SECTION ON THE LINE A-B"
(When the path of section follows an unusual line it is marked as on plan and "titled").

A THREE-QUARTER PLAN WITH REVOLVED SECTIONS

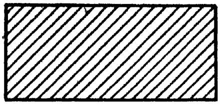


A SECTION IGNORING OBLIQUE PROJECTIONS
(Oblique spoke revolved, oblique handles omitted, square core marked by an X).

(See pages 392–398)

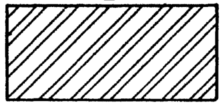
STANDARD HATCHING.

1



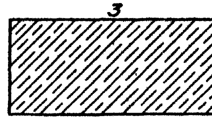
CAST IRON, Also any material if a label or letter designates the kind.

2



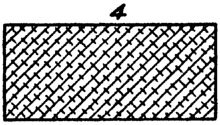
ALL KINDS OF STEEL. (Formerly used for Steel Castings, only)

3



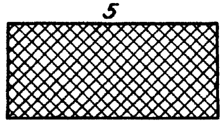
COPPER & COPPER ALLOYS. (As Brass, Bronze, Composition)

4



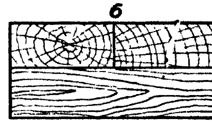
ALUMINUM & ITS ALLOYS. (Magnesium, etc.)

5



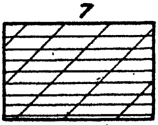
"WHITE METAL." (Tin, Lead, Zinc, alloys) & HEAT INSULATION.

6



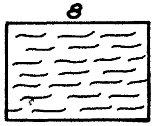
WOOD (Across and with the grain)

7



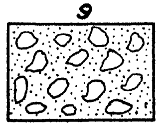
ELECTRIC INSULATION.

8



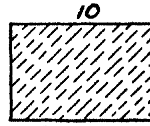
FLEXIBLE MATERIAL. (Fabric, Felt)

9



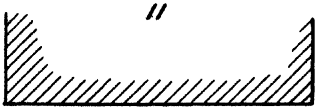
CONCRETE, CEMENT.

10



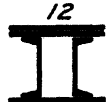
GLASS, PORCELAIN.

11



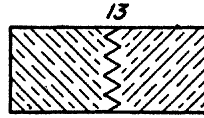
VERY LARGE AREAS. (Hatch around edges only.)

12



VERY SMALL. (Solid black with white divisions.)

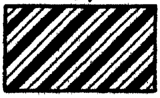
13



AREAS MEETING ON SHORT LINES. (Keep back from edges)

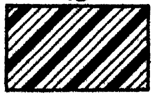
OBSOLETE HATCHING STILL ON MANY DRAWINGS.

14



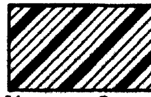
WROUGHT IRON. (Now use No. 2, above, with label.)

15



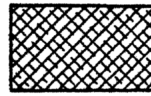
WROUGHT OR FORGED STEEL. (Now use No. 2, above.)

16



NICKEL STEEL. (Now use No. 2, above, with label.)

17

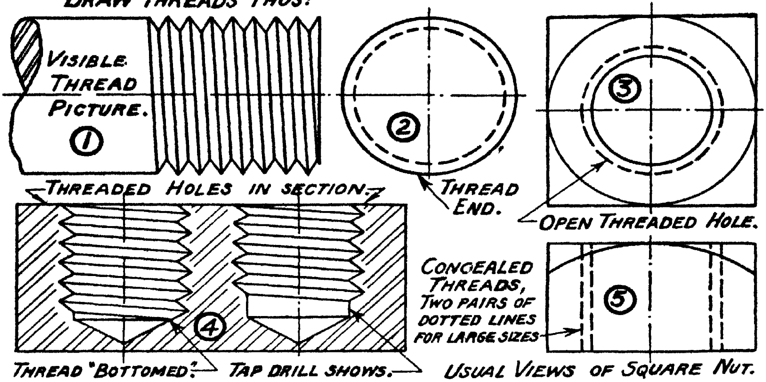


COPPER. (Now use No. 3.)

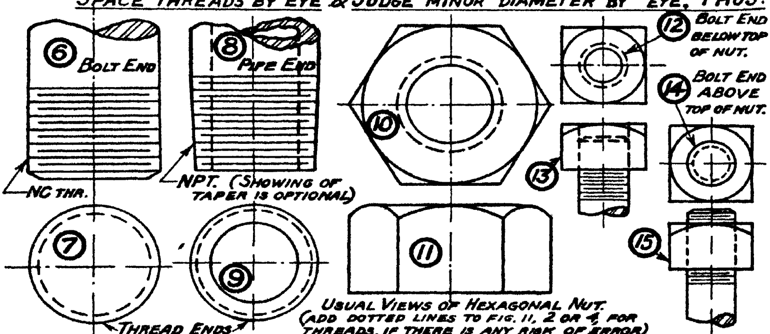
 (See pages 398–399)

STANDARD METHODS OF DRAWING BOLTS & NUTS.

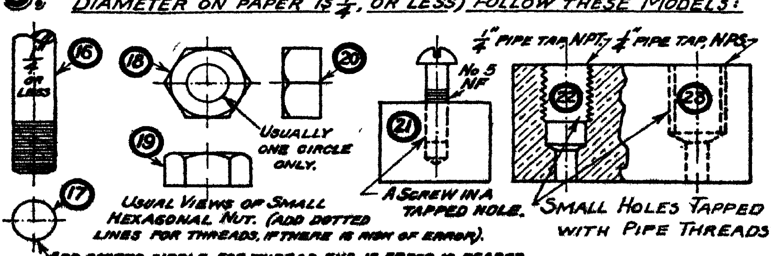
A. ON DRAWINGS SHOWING 6, OR LESS, THREADS PER INCH, FULL SIZE, (OR SCALE DRAWINGS IN WHICH PITCH APPEARS AS $\frac{1}{6}$", OR MORE, ON PAPER), DRAW THREADS THUS:



B. ON DRAWINGS SHOWING 7, OR MORE, THREADS PER INCH, FULL SIZE, (OR SCALE DRAWINGS IN WHICH PITCH APPEARS AS LESS THAN $\frac{1}{6}$", ON PAPER) SPACE THREADS BY EYE & JUDGE MINOR DIAMETER BY EYE, THUS:

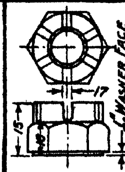


C. SMALL DRAWINGS OF BOLTS & NUTS (USED WHEN NOMINAL DIAMETER ON PAPER IS $\frac{1}{4}$", OR LESS) FOLLOW THESE MODELS:



 (See pages 485–494). 1936

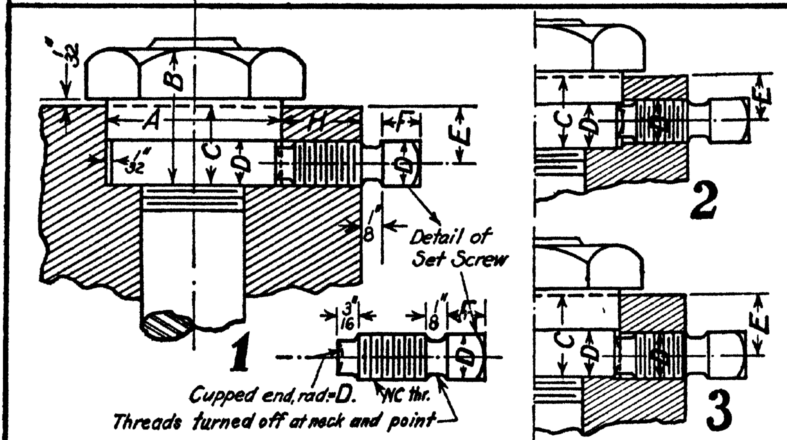
UNITED STATES NATIONAL STANDARD BOLTS AND NUTS.



SCREW NUMBER (1)	MAJOR DIAM. OF THR. (2)	COARSE THREAD SERIES. OLD NAMES (3)	COARSE THREAD SERIES. THREADS PER INCH (4)	COARSE THREAD SERIES. MINOR DIAM. OF THREADS (5)	FINE THREAD SERIES. OLD NAMES (6)	FINE THREAD SERIES. THREADS PER INCH (7)	FINE THREAD SERIES. MINOR DIAM OF THREADS (8)	DIMENSIONS OF REGULAR HEADS AND NUTS. WRENCH SIZE DIA. AC. FLATS MAX. (9)	DIAM. OF HEXAGON ACROSS CORNERS MIN. (10)	DIAM. OF SQUARE ACROSS CORNERS MIN. (11)	HEIGHT OF HEAD (12)	HEIGHT OF NUT (13)	HEIGHT OF JAM NUT (14)	CASTELLATED NUTS. TOTAL HEIGHT OF NUT (15)	HEIGHT OF HEXAGON PLUS WASHER FACE (16)	WIDTH OF SLOTS FOR SPLIT PINS (17)	ACME THREADS, SLOPE 29°, DEPTH = 1/2 PITCH. STANDARD NO. OF THREADS PER INCH RECIPROCAL OF THIS NO. = PITCH IN INCHES (18)	MINOR DIAMETER OF ACME THREAD (19)	NOMINAL SIZE OF BOLT. MAJOR DIAMETER OF THREAD (2)
0	.060	ALSO CALLED "STOVE BOLTS"	–	–	ALSO CALLED "MACHINE SCREWS"	80	.045	5/32	.17	.21	FOR SCREW HEADS SEE P. 549.	3/64	3/64						
1	.073		64	.054		72	.056	5/32	.17	.21		3/64	3/64						
2	.086		56	.064		64	.067	3/16	.21	.25		1/16	1/16						
3	.099		48	.073		56	.077	3/16	.21	.25		1/16	1/16						
4	.112		40	.081		48	.086	1/4	.28	.33		3/32	3/32						
5	.125		40	.094		44	.097	5/16	.34	.42		7/64	7/64						
6	.138		32	.099		40	.107	5/16	.34	.42		7/64	7/64						
8	.164		32	.125		36	.130	11/32	.38	.46		1/8	1/8						
10	.190		24	.139		32	.152	3/8	.41	.50		1/8	1/8						
12	.216		24	.164		28	.172	7/16	.48	.58		5/32	5/32						
(14)	1/4	FOR SLOW SPEED MACHINERY. ONCE CALLED "U.S. STANDARD."	20	.19	FOR HIGH SPEED MACHINERY. ONCE CALLED "S.A.E. STANDARD"	28	.21	3/8	.41	.50	11/64	7/32	5/32	9/32	3/16	5/64	16	.19	1/4
(20)	5/16		18	.24		24	.26	1/2	.55	.67	13/64	17/64	3/16	27/64	15/64	5/64	14	.24	5/16
(24)	3/8		16	.30		24	.33	9/16	.62	.75	1/4	21/64	7/32	13/32	9/32	1/8	12	.28	3/8
	7/16		14	.35		20	.38	5/8	.69	.83	19/64	3/8	1/4	29/64	21/64	1/8	12	.35	7/16
	1/2		13	.40		20	.44	3/4	.83	1.00	21/64	7/16	5/16	9/16	5/8	1/8	10	.40	1/2
	9/16		12	.46		18	.49	7/8	.97	1.16	5/8	1/2	11/32	39/64	27/64	5/32	10	.46	9/16
	5/8		11	.51		18	.56	15/16	1.03	1.24	27/64	35/64	3/8	23/32	15/32	5/32	8	.50	5/8
	3/4		10	.63		16	.67	1 1/8	1.24	1.49	1/2	21/32	7/16	13/16	9/16	5/32	8	.63	3/4
	7/8		9	.74		14	.79	1 5/16	1.45	1.74	19/32	49/64	1/2	29/32	21/32	5/32	8	.75	7/8
	1		8	.85		14	.91	1 1/2	1.65	1.99	31/32	7/8	9/16	1	3/4	5/32	5	.80	1
	1 1/8		7	.95		12	1.02	1 11/16	1.86	2.24	3/4	1	5/8	1 5/32	27/32	7/32	5	.93	1 1/8
	1 1/4		7	1.07		12	1.15	1 7/8	2.07	2.49	27/32	1 3/32	3/4	1 1/4	15/16	7/32	5	1.05	1 1/4
	1 1/2		6	1.30		12	1.40	2 1/4	2.48	2.99	1	1 5/16	7/8	1 1/2	1 1/8	1/4	4	1.25	1 1/2
	1 3/4		5	1.50				2 5/8	2.89	3.48	1 5/32	1 17/32	1	ALL FINISHED HEADS & NUTS HAVE THE 1/64" WASHER FACE, DIAMETER OF WRENCH SIZE, AS SHOWN ON THE CASTELLATED NUT ABOVE. IT IS NOT SHOWN ON DRAWINGS.			4	1.50	1 3/4
	2		4 1/2	1.73				3	3.31	3.99	1 11/32	1 3/4	1 1/8				4	1.75	2
	2 1/4		4 1/2	1.98				3 3/8	3.72	4.48	1 1/2	1 31/32	1 1/4				2	1.75	2 1/4
	2 1/2		4	2.19				3 3/4	4.13	4.98	1 21/32	2 3/16	1 1/2				2	2.00	2 1/2
	2 3/4		4	2.44				4 1/8	4.55	5.48	1 13/16	2 13/32	1 5/8				2	2.25	2 3/4
	3		4	2.69				4 1/2	4.96	5.98	2	2 5/8	1 3/4				2	2.50	3
	3 1/2		4	3.19				5 1/4	5.80	7.08	2 11/16	3 1/16	2 1/8				2	3.00	3 1/2
	4		4	3.69				6	6.64	8.12	3 1/8	3 1/2	2 1/2				2	3.50	4
	4 1/2		4	4.19				6 3/4	7.46	9.16	3 1/2	3 7/8	2 3/4				2	4.00	4 1/2

(See pages 475,476)

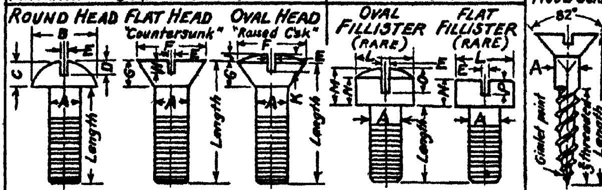
STANDARD LOCK NUTS & SET SCREWS



Diameter of Bolt	See Figure	A	B	C	D	E	F	Smallest H Steel, Brass.	Smallest H Cast Iron.
1/2	1	13/16	7/8	5/8	3/8	7/16	3/8	3/8	7/16
9/16	1	7/8	7/8	5/8	3/8	7/16	3/8	3/8	7/16
5/8	2	1	1	11/16	7/16	7/16	7/16	7/16	1/2
3/4	2	1 1/8	1 1/8	11/16	7/16	7/16	7/16	7/16	1/2
7/8	1	1 5/16	1 1/4	3/4	1/2	1/2	1/2	1/2	5/8
1	1	1 1/2	1 3/8	3/4	1/2	1/2	1/2	1/2	5/8
1 1/8	1	1 11/16	1 3/8	13/16	1/2	9/16	1/2	1/2	5/8
1 1/4	3	1 7/8	1 5/8	13/16	9/16	9/16	9/16	9/16	11/16
1 1/2	2	2 1/4	2	7/8	9/16	9/16	9/16	9/16	11/16
1 3/4	1	2 5/8	2 1/4	15/16	5/8	5/8	5/8	5/8	3/4
2	3	3	2 1/2	1	3/4	11/16	3/4	3/4	7/8
2 1/4	1	3 3/8	2 3/4	1 1/8	3/4	3/4	3/4	3/4	7/8
2 1/2	1	3 3/4	3 3/8	1 1/8	3/4	3/4	3/4	3/4	7/8
2 3/4	1	4 1/8	4 1/8	1 1/4	7/8	13/16	7/8	7/8	1
3	1	4 1/2	4 1/2	1 1/4	7/8	13/16	7/8	7/8	1
3 1/2	1	5 1/4	5 1/4	1 3/8	1	7/8	1	1	1 1/4
4	1	6	6	1 3/8	1	7/8	1	1	1 1/4

(See page 477)

Standard Machine Screw Heads & Wood Screws.



Screw Number	Approximate Size	Threads per Inch: Machine Screws	Threads per Inch: Wood Screws	Tap Drill Diameters for Machine Screws	For Machine Screws & Wood Screws — Round Head: A	B	C	D	Flat Head "Countersunk": E	F	G	Oval Head "Raised C'sk": H	For Machine Screws Only — Oval Fillister (Rare): J	K	L	Flat Fillister (Rare): M	N	Wood Screws: O	P	Screw Number
0		80	32	.047	.060	.106	.046	.034	.025	.112	.030	.013	.018	.028	.090	.050	.038	.025	.018	0
1		72	28	.060	.073	.130	.056	.038	.028	.138	.037	.016	.022	.035	.111	.061	.046	.030	.023	1
2		64	26	.070	.086	.154	.064	.042	.030	.164	.045	.019	.026	.041	.132	.073	.055	.036	.027	2
3		56	24	.080	.099	.178	.072	.046	.032	.190	.052	.022	.030	.048	.153	.084	.063	.042	.032	3
4		48	22	089	.112	.202	.080	.050	.034	.216	.060	.025	.033	.054	.175	.095	.072	.048	.036	4
5	1/8"	44	20	.100	.125	.226	.088	.054	.037	.242	.067	.028	.037	.061	.196	.107	.083	.053	.040	5
6		40	18	111	.138	.250	.092	.058	.039	.268	.075	.031	.041	.067	.217	.118	.089	.059	.044	6
7		–	16	–	.151	.274	.105	.063	.041	.294	.082	.034	.044	.074	–	–	–	–	–	7
8		36	15	136	.164	.298	.113	.067	.043	.320	.090	.037	.048	.080	.260	.141	.106	.071	.053	8
9		–	14	–	.177	.322	.121	.071	.046	.346	.097	.041	.052	.087	–	–	–	–	–	9
10	3/16"	32	13	.156	.190	.346	.130	.075	.048	.372	.105	.044	.056	.093	.303	.164	.124	.082	.062	10
11		–	12	–	.203	.370	.138	.079	.050	.398	.113	.047	.059	.100	–	–	–	–	–	11
12		28	11	.178	.216	.394	.146	.083	.052	.424	.120	.050	.063	.107	.345	.187	.141	.093	.070	12
14	1/4"	"	10	.204	.242	.443	.162	.093	.057	.476	.135	.056	.071	.120	.388	.210	.158	.105	.079	14
16		"	9	.230	.268	.491	.178	.100	.061	.528	.150	.062	.078	.133	.431	.233	.175	.116	.087	16
18		24	8	.246	.294	.539	.195	.108	.066	.580	.164	.069	.085	.146	.473	.255	.192	.128	.096	18
20	5/16"	"	"	.272	.320	.587	.212	.116	.070	.632	.179	.075	.098	.160	.516	.278	.208	.140	.104	20
24	3/8"	"	7	.324	.372	.683	.244	.133	.079	.736	.209	.087	.108	.186	.601	.324	.244	.162	.122	24

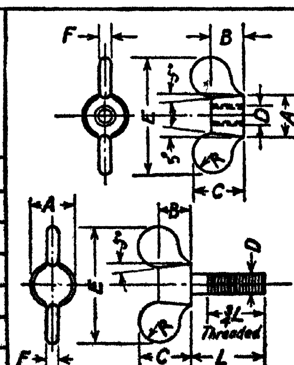
For similar heads on larger sizes see p. 550. For Hex. & Square Machine Screw Nuts see p. 547.
Oval & Flat Fillister Heads are now rarely used. Machine Screws 14–24 are little used.

7

(See page 478)

Standard Wing Nuts and Wing Screws.

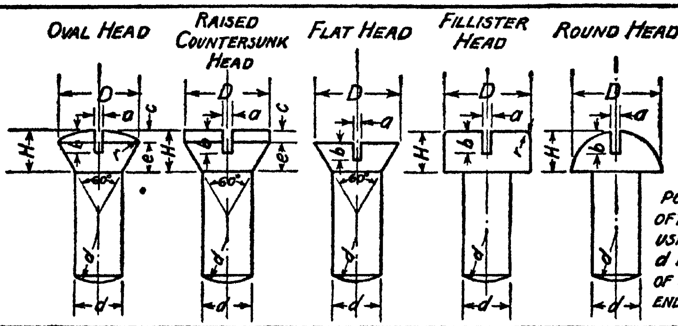
Size: In Inches D	Size: Screw Number	U.S. Standard Threads per Inch	Diameter A	Thickness B	Wing Height C	Wing Spread E	Wing Thickness F	Wing Radius R
1/8	5	40	.28	3/16	.328	3/4	.10	1/8
3/16	10	24	.36	1/4	.42	15/16	.12	5/32
1/4	14	20	.44	5/16	.531	1 1/8	14	3/16
5/16	20	18	.52	3/8	.656	1 7/16	.15	1/4
3/8	24	16	.60	7/16	.765	1 11/16	.17	9/32
7/16		14	.68	1/2	.875	1 31/32	.18	21/64
1/2		13	.76	9/16	1.0	2 1/4	.20	3/8



8

(See page 476)

STANDARD ORDNANCE SCREWS.



USE NF THREADS.

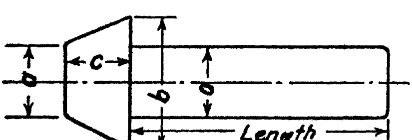
POINTS ARE OFTEN ROUNDED USING DIAMETER *d* FOR THE RADIUS OF THE SPHERICAL END AS SHOWN.

d	D	H	a	b	c	e	r
1/2"	7/8"	7/16"	0."05	1/4"	7/64"	21/64"	1/16"
5/8	1 1/16	1/2	1/16	1/4	1/8	3/8	1/16
3/4	1 1/4	9/16	0.08	5/16	1/8	7/16	1/16
7/8	1 7/16	5/8	0.10	5/16	9/64	31/64	5/64
1	1 5/8	11/16	0.10	3/8	9/64	35/64	5/64
1 1/8	1 13/16	3/4	1/8	3/8	5/32	19/32	5/64
1 1/4	2	13/16	1/8	7/16	5/32	21/32	5/64
1 1/2	2 3/8	15/16	0.15	1/2	3/16	3/4	3/32
1 3/4	2 3/4	1 1/16	3/16	9/16	13/64	55/64	7/64
2	3 1/8	1 3/16	3/16	5/8	7/32	31/32	7/64

9

(See page 478)

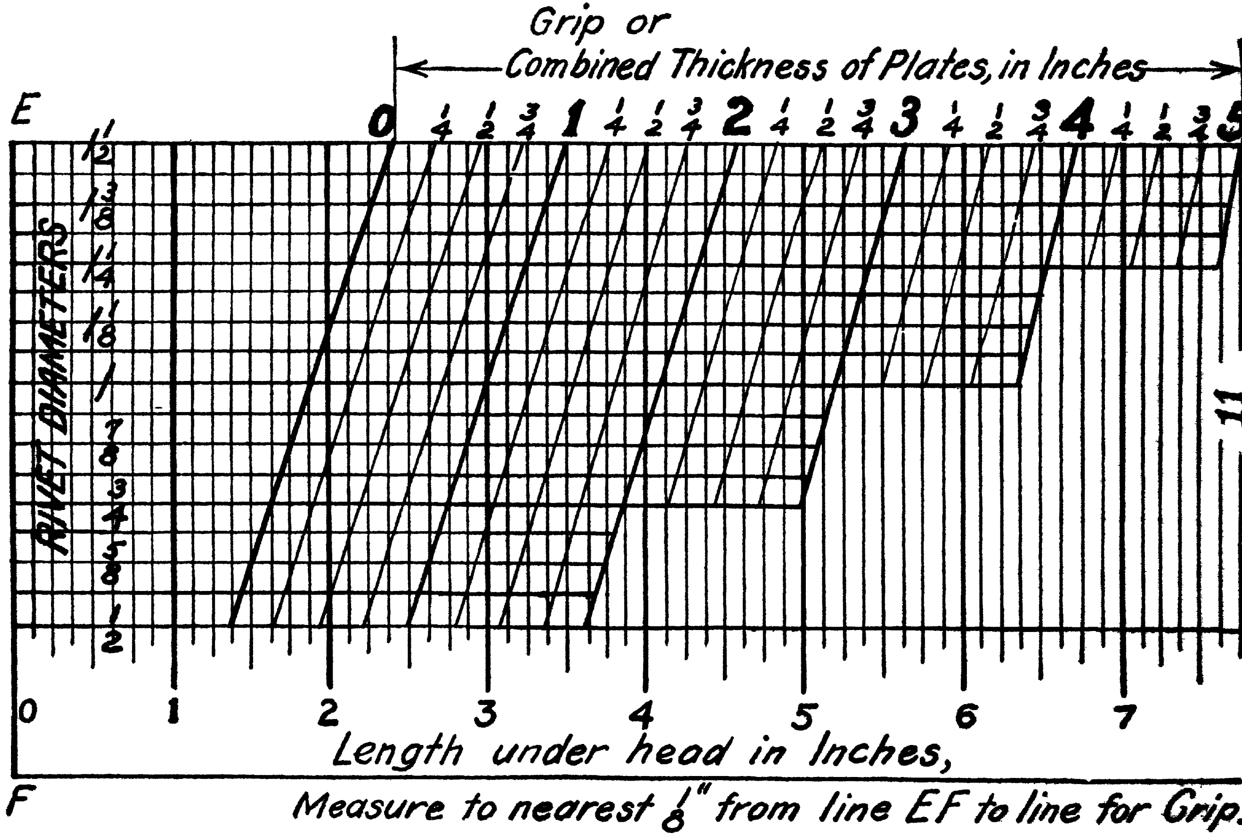
STANDARD BOILER RIVETS.



THE LENGTH IS TO BE FOUND FROM THE DIAGRAM OPPOSITE, USING DIAMETER BEFORE DRIVING AND THE PROPER GRIP.

a	1/2"	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 7/16	1 1/2
b	15/16"	1	1 1/8	1 1/4	1 5/16	1 7/16	1 1/2	1 5/8	1 3/4	1 13/16	1 15/16	2	2 1/8	2 1/4	2 3/8	2 1/2	2 5/8
c	7/16"	1/2	9/16	5/8	5/8	11/16	11/16	3/4	13/16	13/16	7/8	7/8	15/16	1	1 1/16	1 1/8	1 3/16

(See page 499)


Grip or
Combined Thickness of Plates, in Inches
0 1/4 1/2 3/4 1 1/4 1/2 3/4 2 1/4 1/2 3/4 3 1/4 1/2 3/4 4 1/4 1/2 3/4 5
E
F
RIVET DIAMETERS
1 1/2
1 3/8
1 1/4
1 1/8
1
7/8
3/4
5/8
1/2
0 1 2 3 4 5 6 7
Length under head in Inches,
Measure to nearest 1/8" from line EF to line for Grip.
11

STANDARD WROUGHT PIPE
IRON OR STEEL

Nominal Diameter	Threads per inch	Outside Diameter	Inside Diameter: Standard	Inside Diameter: Extra Strong	Inside Diameter: Double E.S.	Weight per ft., lbs.: Standard	Weight per ft., lbs.: Extra Strong	Weight per ft., lbs.: Double E.S.
1/8	27	.405	.27	.205		.241	.29	
1/4	18	.54	.364	.294		.42	.54	
3/8	18	.675	.494	.421		.559	.74	
1/2	14	.84	.623	.542	.244	.837	1.09	1.7
3/4	14	1.05	.824	.736	.422	1.12	1.39	2.44
1	11 1/2	1 5/16	1.048	.951	.587	1.68	2.17	3.65
1 1/4	11 1/2	1 21/32	1.38	1.272	.885	2.24	3.	5.2
1 1/2	11 1/2	1 29/32	1.611	1.494	1.088	3.68	3.63	6.4
2	11 1/2	2 3/8	2.067	1.933	1.491	4.61	5.02	9.
2 1/2	8	2 7/8	2.468	2.315	1.755	5.74	7.67	13.7
3	8	3 1/2	3.067	2.892	2.284	7.54	10.3	18.6
3 1/2	8	4	3.548	3.358	2.716	9.	12.5	22.7
4	8	4 1/2	4.026	3.818	3.136	10.7	15.	27.5
4 1/2	8	5	4.508	4.28	3.564	12.3	17.2	33.3
5	8	5 9/16	5.045	4.813	4.063	14.5	20.5	38.1
6	8	6 5/8	6.065	5 3/4	4 7/8	18.8	28.6	53.1
7	8	7 5/8	7.023	6 5/8	5 7/8	23.3		
8	8	8 5/8	7.982	7 5/8	6 7/8	28.2		
9	8	9 5/8	8.937	8 5/8		33.7		
10	8	10 3/4	10.02	9 3/4		40.1		
11	8	12	11 1/4			46.		
12	8	12 3/4	12			49		
14	8	14	13 1/4			53.9		
15	8	15	14 1/4			57.9		
16	8	16	15 1/4			61.8		

(See page 503)

DECIMAL
EQUIVALENTS OF AN INCH

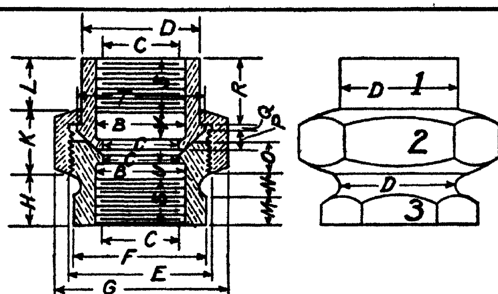
	1/32	.031
	1/16	.062
	3/32	.094
1/8		.125
	5/32	.156
	3/16	.188
	7/32	.219
1/4		.25
	9/32	.281
	5/16	.312
	11/32	.344
3/8		.375
	13/32	.406
	7/16	.438
	15/32	.469
1/2		.5
	17/32	.531
	9/16	.562
	19/32	.594
5/8		.625
	21/32	.656
	11/16	.688
	23/32	.719
3/4		.75
	25/32	.781
	13/16	.812
	27/32	.844
7/8		.875
	29/32	.906
	15/16	.938
	31/32	.969

(See page 505)

Birmingham WIRE GAUGE

No.	Size
0	.34
1	.3
2	.284
3	.259
4	.238
5	.22
6	.203
7	.18
8	.165
9	.148
10	.134
11	.12
12	.109
13	.095
14	.083
15	.072
16	.065
17	.058
18	.049
19	.042
20	.035
21	.032
22	.028
23	.025
24	.022
25	.02
26	.018
27	.016
28	.014
30	.012
31	.01

STANDARD SCREW PIPE UNIONS

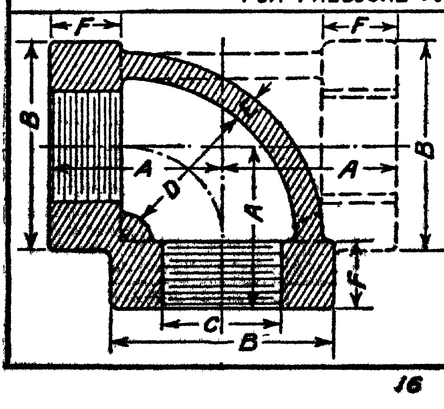


PIPE DIAM NOMINAL	PIPE DIAM OUTSIDE	THREADS PER INCH	B	C	D	E	ACROSS FLATS F	ACROSS FLATS G	H	K	L	M	N	O	P	Q	R	S	T	U	V
1/8	13/32	27	5/16	5/16	1/2	23/32	18/32	7/8	5/16	13/32	9/32	3/16	1/8	3/16	1/8	1/16	3/8	1/4	5/8	—	—
1/4	35/64	18	15/32	15/32	11/16	29/32	25/32	1 1/16	7/16	7/16	11/32	1/4	3/16	1/4	1/8	1/16	7/16	5/16	13/16	—	—
3/8	11/16	18	9/16	9/16	13/16	1 3/32	31/32	1 1/4	15/32	19/32	3/8	1/4	7/32	9/32	3/16	1/16	1/2	3/8	1	—	—
1/2	27/32	14	3/4	3/4	1 1/16	1 3/8	1 1/4	1 5/8	17/32	5/8	1/2	5/16	7/32	5/16	7/32	1/16	5/8	7/16	1 1/4	—	—
3/4	1 3/64	14	15/16	15/16	1 5/16	1 5/8	1 7/16	1 13/16	19/32	3/4	19/32	3/8	7/32	3/8	7/32	3/32	3/4	1/2	1 1/2	—	—
1	1 5/16	11 1/2	1 3/16	1 3/16	1 9/16	1 7/8	1 5/8	2 3/16	3/4	27/32	23/32	7/16	5/16	3/8	9/32	1/8	7/8	5/8	1 3/4	—	—
1 1/4	1 43/64	11 1/2	1 1/2	1 1/2	1 15/16	2 1/4	2	2 9/16	7/8	15/16	15/16	1/2	3/8	7/16	1/4	3/16	1 1/8	3/4	2 1/8	—	—
1 1/2	1 29/32	11 1/2	1 29/32	1 3/4	2 1/4	2 5/8	2 3/8	2 15/16	1 1/32	1 3/32	1 3/32	9/16	15/32	1/2	5/16	3/16	1 5/16	7/8	2 1/2	5/16	1/2
2	2 3/8	11 1/2	2 3/8	2 7/32	2 3/4	3 5/32	2 15/16	3 1/2	1 1/8	1 5/16	1 1/4	5/8	1/2	5/8	11/32	7/32	1 1/2	1	3	3/8	9/16
2 1/2	2 7/8	8	2 7/8	2 21/32	3 5/16	3 13/16	3 1/2	4 1/4	1 5/16	1 17/32	1 11/32	11/16	5/8	3/4	7/16	1/4	1 5/8	1 1/8	3 5/8	7/16	5/8
3	3 1/2	8	3 1/2	3 5/16	4	4 5/8	4 1/4	5	1 3/8	1 13/16	1 7/16	3/4	5/8	7/8	1/2	5/16	1 3/4	1 1/4	4 3/8	1/2	13/16

 (See page 505)

STANDARD SCREW ELBOWS & TEES.

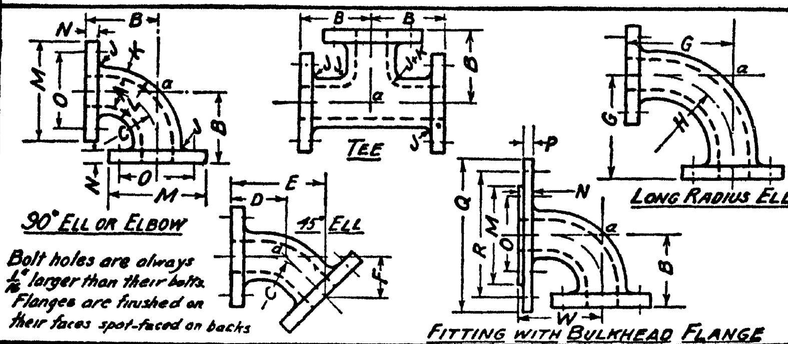
FOR PRESSURE TO 200 LBS PSI.



SIZE	A	B	C	D	E	F
1 1/2	1 7/8	2 11/16	1.9	2	3/16	5/8
2	2 3/16	3 5/16	2 3/8	2 1/2	3/16	11/16
2 1/2	2 1/2	3 13/16	2 7/8	3	7/32	11/16
3	2 15/16	4 5/8	3 1/2	3 5/8	7/32	3/4
3 1/2	3 5/16	5 1/4	4	4 1/8	1/4	13/16
4	3 3/4	5 3/4	4 1/2	4 5/8	1/4	7/8
4 1/2	4 1/8	6 3/8	5	5 1/8	5/16	1
5	4 1/2	7 1/16	5 9/16	5 11/16	5/16	1 1/8
6	5 1/4	8 1/8	6 5/8	6 3/4	5/16	1 1/16

 (See page 506)

SHAPES OF STANDARD ELLS & TEES. DIMENSIONS OF CAST IRON FITTINGS.



Bolt holes are always 1/16" larger than their bolts. Flanges are finished on their faces spot-faced on backs

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
FOR ANY MATERIAL & PRESSURE										CAST IRON FOR MERCHANT SHIPS & SHORE USE																		
SIZE		L & T		45° Ell			Long R			PRESSURES 0-100 lbs (Except Sizes 8 to 11½ are limited to 50 lbs)															101-200 lbs (with ribs)			
Nominal	Inside	C. to face	Radius	C. to face	Offset	Deflect	C. to face	Radius	All fillets	Thick's	O D	Standard Flange and bolts						Bulkhead Flange and bolts							Thick's	O. D.	Fl Th	Note
	A	B	C	D	E	F	G	H	J	K	L	M	N	O	No	Dia	Chord	P	Q	R	W	No	Dia	Chord	K	L	N	
1¼	1½	4¼	2¾	2½	4¼	1¾	6¼	4¾	¼	3/8	2¼	4½	5/8	3 3/8	4	½	2.35	5/8	7 1/8	6	4¾	8	½	2.30	7/16	2 3/8	¾	
1½	2	4¾	3¼	2¾	4¾	2	6½	5	¼	3/8	2¾	5 1/16	5/8	3 15/16	6	½	1.97	5/8	7 11/16	6 9/16	5	8	½	2.51	½	3	7/8	
2	2½	5	3½	3	5 1/8	2 1/8	7	5½	¼	½	3½	5 3/16	¾	4 7/16	6	½	2.22	¾	8 3/16	7 1/16	5¼	10	½	2.18	½	3½	7/8	
2½	3	5¾	4	3	5 1/8	2 1/8	7½	6	¼	½	4	6 1/8	¾	5	6	½	2.50	¾	8¾	7 5/8	6	10	½	2.36	9/16	4 1/8	1	
3	3½	6	4¼	3½	6	2½	8½	7	¼	½	4½	6 5/8	13/16	5½	8	½	2.10	¾	9¼	8 1/8	6¾	10	½	2.51	9/16	4 5/8	1	
3½	4	6¼	4½	3¾	6 3/8	2 5/8	9	7½	¼	½	5	7 3/16	7/8	6 1/16	8	½	2.32	¾	9 13/16	8 9/16	7¼	10	½	2.89	5/8	5¼	1 1/8	
4	4½	6½	4¾	4	6 7/8	2 7/8	9½	8	¼	½	5½	7 11/16	7/8	6 9/16	8	½	2.51	¾	10 5/16	9 1/16	7½	12	½	2.39	5/8	5¾	1 1/8	
4½	5	7	5	4	6 7/8	2 7/8	10½	9	3/8	½	6	8 3/16	7/8	7 1/16	10	½	2.18	¾	10 13/16	9 11/16	8	12	½	2.52	11/16	6 3/8	1¼	
5	5½	7¼	5¼	4	6 7/8	2 7/8	11½	9½	3/8	½	6½	9 1/16	7/8	7 13/16	10	5/8	2.41	¾	12 3/8	10 11/16	8½	12	5/8	2.84	11/16	6 7/8	1¼	
5½	6	8	6	4¼	7¼	3	12	10	3/8	½	7	9 3/16	1	8 5/16	10	5/8	2.57	¾	12 7/8	11 7/16	9½	12	5/8	2.96	¾	7½	1¼	
6	6½	8¼	6¼	4½	7¾	3¼	13	10½	3/8	9/16	7 5/8	10 1/8	1	8 7/8	12	5/8	2.30	¾	13 7/16	12	9 5/8	12	5/8	3.11	¾	8	1 3/8	
6½	7	8¾	6½	4½	7¾	3¼	13½	11	3/8	9/16	8 1/8	10 5/8	1	9 3/8	12	5/8	2.43	¾	13 15/16	12½	10¼	12	5/8	3.24	13/16	8 5/8	1 3/8	
7	7½	9	6¾	4¾	8 1/8	3 3/8	14	12	3/8	9/16	8 5/8	11 5/16	1 1/8	10	12	5/8	2.59	¾	14 5/8	13 5/16	11	14	5/8	2.94	13/16	9 1/8	1½	
7½	8	9¾	7¼	5	8½	3½	15	12½	½	9/16	9 1/8	11 7/8	1 1/8	10 9/16	12	5/8	2.73	¾	15 3/16	13¾	11¼	14	5/8	3.06	7/8	9¾	1½	
8	8½	10	7½	5	8½	3½	15½	13	½	5/8	9¾	12 3/8	1 1/8	11 1/16	14	5/8	2.46	¾	15 15/16	14¼	11¾	14	5/8	3.17				
8½	9	10½	8	5¾	9 7/8	4 1/8	16½	14	½	5/8	10¼	12 15/16	1¼	11 5/8	14	5/8	2.59	7/8	16¼	14 13/16	12½	14	5/8	3.30				
9	9½	10¾	8¼	6	10¼	4¼	17	14½	½	5/8	10¾	13 7/16	1¼	12 3/8	14	¾	2.75	7/8	16 15/16	15 9/16	13	14	¾	3.43				
9½	10	11	8½	6	10¼	4¼	18	15	½	5/8	11¼	14½	1¼	12 15/16	14	¾	2.88	7/8	18 1/8	17 1/8	13¼	14	¾	3.21				
10	10½	11¼	8¾	6½	11 1/8	4 5/8	19	16	½	5/8	11¾	15	1¼	13 7/16	15	¾	2.75	7/8	19 3/8	17 5/8	13¾	16	¾	3.44				
10½	11	11¾	9	6½	11 5/8	4 5/8	19½	16½	½	5/8	12¼	15½	1¼	13 15/16	15	¾	2.90	7/8	19 7/8	18	14¼	16	¾	3.54				
11½	12	12¾	9¾	7	12	5	21	18	½	5/8	13¼	16 9/16	1¼	15	16	¾	2.93	7/8	21	19¼	15	16	¾	3.75				

Note: Columns 16 and 18-21 of p 555 opposite, also apply to these heavy C.I. fittings. Ribs join adjacent flanges.

A Rib of thickness equal to K, Column 26, here.

(See pages 507-509) 1936

FLANGED COMPOSITION PIPE FITTINGS
AND SEAMLESS DRAWN BRASS & COPPER TUBES

Columns 1–13: Size, and For Pressures 0–100. Columns 5–9 and 11–25, Page 554, also apply.

1 Nominal Size	2 Actual Inside D. A	3 Center to face B	4 Radius of bend C	5 Fillet radius J	6 Thickness K	7 Outside Dia. L	8 Flange & Bolts: Diameter M	9 Flange & Bolts: Thickness N	10 Flange & Bolts: Pitch Circle O	11 Flange & Bolts: No. of Bolts	12 Flange & Bolts: Diameter	13 Flange & Bolts: Chord dist.
1/4	1/2	3 1/4	2	3/16	3/16	7/8	3 1/4	3/8	2 1/8	3	1/2	1.84
1/2	3/4	3 1/2	2 1/4	3/16	3/16	1 1/8	3 9/16	3/8	2 7/16	3	1/2	2.11
3/4	1	3 3/4	2 1/4	3/16	3/16	1 3/8	3 13/16	7/16	2 11/16	4	1/2	1.90
1	1 1/4	4	2 1/2	3/16	3/16	1 5/8	4 1/4	7/16	3 1/8	4	1/2	2.21
1 1/4	1 1/2	4 1/4	2 3/4	1/4	3/16	1 7/8	4 1/2	7/16	3 3/8	4	1/2	2.39
1 1/2	2	4 3/4	3 1/4	1/4	3/16	2 3/8	5 1/16	7/16	3 15/16	6	1/2	1.97
2	2 1/2	5	3 1/2	1/4	1/4	3	5 9/16	7/16	4 7/16	6	1/2	2.22
2 1/2	3	5 3/4	4	1/4	1/4	3 1/2	6 1/8	1/2	5	6	1/2	2.50
3	3 1/2	6	4 1/4	1/4	1/4	4	6 5/8	1/2	5 1/2	8	1/2	2.10
3 1/2	4	6 1/4	4 1/2	1/4	1/4	4 1/2	7 3/16	1/2	6 1/16	8	1/2	2.32
4	4 1/2	6 1/2	4 3/4	1/4	1/4	5	7 11/16	1/2	6 3/16	8	1/2	2.51
4 1/2	5	7	5	3/8	5/16	5 5/8	8 3/16	1/2	7 1/16	10	1/2	2.18
5	5 1/2	7 1/4	5 1/4	3/8	5/16	6 1/8	9 1/16	9/16	7 13/16	10	5/8	2.41
5 1/2	6	8	6	3/8	5/16	6 5/8	9 9/16	9/16	8 5/16	10	5/8	2.57
6	6 1/2	8 1/4	6 1/4	3/8	5/16	7 1/8	10 1/8	9/16	8 7/8	12	5/8	2.30
6 1/2	7	8 3/4	6 1/2	3/8	3/8	7 3/4	10 5/8	9/16	9 3/8	12	5/8	2.43
7	7 1/2	9	6 3/4	3/8	3/8	8 1/4	11 5/16	9/16	10	12	5/8	2.59
7 1/2	8	9 3/4	7 1/4	1/2	3/8	8 3/4	11 7/8	5/8	10 9/16	12	5/8	2.73
8	8 1/2	10	7 1/2	1/2	3/8	9 1/4	12 3/8	5/8	11 1/16	14	5/8	2.46
8 1/2	9	10 1/2	8	1/2	3/8	9 3/4	12 15/16	5/8	11 5/8	14	5/8	2.59
9	9 1/2	10 3/4	8 1/4	1/2	3/8	10 1/4	13 15/16	11/16	12 3/8	14	3/4	2.75
9 1/2	10	11	8 1/2	1/2	3/8	10 3/4	14 1/2	11/16	12 15/16	14	3/4	2.88
10	10 1/2	11 1/4	8 3/4	1/2	3/8	11 1/4	15	11/16	13 7/16	15	3/4	2.79

Columns 14–27: For Pressures 101–400 (not used for Steam). Can be cast in Steel for Steam. Seamless Drawn Brass & Copper Tubes. Thickness by formula $T = \frac{\text{Pressure} \times \text{Diam}}{2(4000 + \text{Pressure})}$. Minimum T is .065.

Nominal Size	14 Thickness K	15 Outside Dia. L	16 Flange & Bolts: Diameter M	17 Flange & Bolts: Thickness N	18 Flange & Bolts: Pitch Circle O	19 Flange & Bolts: No. of Bolts	20 Flange & Bolts: Diameter	21 Flange & Bolts: Chord dist.	22 Actual Outside D.	23 For Pressures 100	24 For Pressures 200	25 For Pressures 300	26 For Pressures 450	27 For Pressures 600
1/4	1/4	1	3 3/4	11/16	2 5/8	3	1/2	2.27	.54					.065
1/2	1/4	1 1/4	4	11/16	2 7/8	4	1/2	2.03	.84					.065
3/4	1/4	1 1/2	4 5/16	11/16	3 3/16	4	1/2	2.25	1.05				.065	.068
1	1/4	1 3/4	5 1/16	3/4	3 3/4	5	5/8	2.20	1 5/16			.065	.066	.086
1 1/4	1/4	2	5 3/8	13/16	4 1/16	5	5/8	2.39	1 21/32			.065	.084	.108
1 1/2	5/16	2 5/8	5 15/16	13/16	4 5/8	6	5/8	2.31	1 29/32		.065	.066	.096	.124
2	5/16	3 1/8	6 1/2	13/16	5 3/16	7	5/8	2.25	2 3/8		.065	.083	.120	.155
2 1/2	5/16	3 5/8	7 9/16	15/16	6	8	3/4	2.30	2 7/8	.065	.068	.100	.145	.187
3	5/16	4 1/8	8 1/8	15/16	6 9/16	8	3/4	2.51	3 1/2	.065	.083	.122	.177	.228
3 1/2	5/16	4 5/8	8 11/16	1	7 1/8	9	3/4	2.44	4	.065	.095	.140	.202	.261
4	3/8	5 1/4	9 1/4	1	7 11/16	9	3/4	2.63	4 1/2	.065	.107	.157	.228	.293
4 1/2	3/8	5 3/4	9 13/16	1	8 1/4	10	3/4	2.55	5	.065	.119	.174	.255	.326
5	3/8	6 1/4	10 3/8	1 1/16	8 13/16	11	3/4	2.48	5 9/16	.068	.132	.194	.281	.363
5 1/2	7/16	6 7/8	11 3/8	1 1/8	9 5/8	11	7/8	2.71	6 1/8	.075	.146	.214	.310	.399
6	7/16	7 3/8	11 15/16	1 3/16	10 3/16	12	7/8	2.64	6 5/8	.081	.158	.231	.335	.432
6 1/2	7/16	7 7/8	12 9/16	1 1/4	10 13/16	12	7/8	2.80	7 1/8	.087	.170	.249	.360	.465
7	1/2	8 1/2	13 1/8	1 1/4	11 3/8	12	7/8	2.94	7 5/8	.093	.182	.266	.386	.497
7 1/2	1/2	9	14 3/16	1 1/4	12 3/16	12	1	3.15	8 1/8	.099	.193	.283	.411	.530
8	1/2	9 1/2	14 3/4	1 5/16	12 3/4	13	1	3.05	8 5/8	.105	.205	.301	.436	.563
8 1/2	9/16	10 1/8	15 5/16	1 5/16	13 5/16	13	1	3.19	9 1/8	.111	.217	.318	.461	.595
9	9/16	10 5/8	15 7/8	1 3/8	13 7/8	14	1	3.09	9 5/8	.117	.229	.336	.487	.628
9 1/2	5/8	11 1/4	16 7/8	1 7/16	14 7/16	15	1	3.00	10 1/4	.125	.244	.358	.518	.668
10	11/16	11 7/8	17	1 7/16	15	15	1	3.12	10 3/4	.131	.256	.375	.544	.701

Called by Inside Dia.

Size (A)	B	C	J	0–100: K	0–100: L	0–100: M	0–100: N	0–100: O	0–100: No. of Bolts	0–100: Diameter	0–100: Chord dist.	101–300: K	101–300: L	101–300: M	101–300: N	101–300: O	101–300: No. of Bolts	101–300: Diameter	101–300: Chord dist.
11	11 3/4	9	5/8	3/8	11 3/4	15 1/2	11/16	13 15/16	15	3/4	2.90	11/16	12 3/8	17 9/16	1 5/16	16 3/8	15	1 1/8	3.40
12	12 3/4	9 3/4	5/8	3/8	12 3/4	16 9/16	11/16	15	16	3/4	2.93	3/4	13 1/2	19 3/4	1 3/8	17 9/16	16	1 1/8	3.43
13	13 1/4	10 1/4	5/8	3/8	13 3/4	17 5/8	3/4	16 1/16	18	3/4	2.79								
14	14	11	5/8	7/16	14 7/8	19 1/8	3/4	17 3/8	19	7/8	2.86								
15	15	12	5/8	7/16	15 7/8	20 1/8	3/4	18 3/8	20	7/8	2.87								

← These Fittings are used with Brazed Copper Pipes.

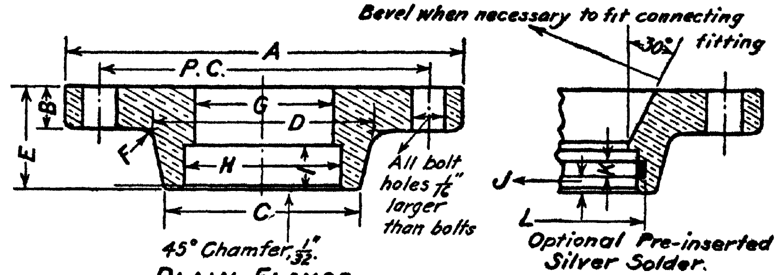
Thickness of Brazed Pipes by this table →

Size	Thickness for Pressures 50	100	150	300
11	.069	.138	.206	.413
12	.075	.150	.225	.450
13	.081	.163	.243	.488
14	.088	.175	.263	.525
15	.094	.188	—	—

1936.

(See pages 509-510)

Composition Silver Soldered Flanges for Copper and Copper-Nickel Alloy Tubes and Pipes



PLAIN FLANGE

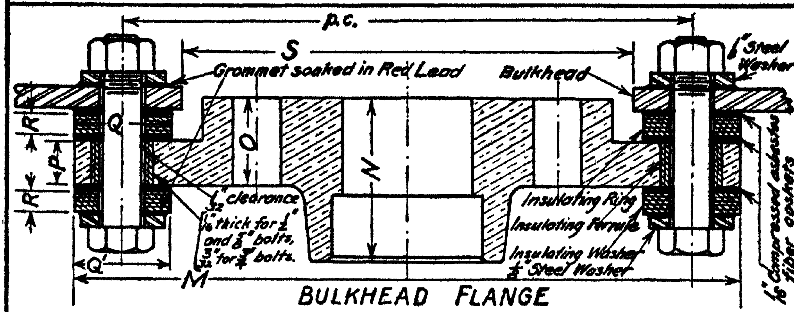
THIS PAGE FOR PRESSURE TO 100 LBS PSI AND MAXIMUM TEMP. 425° F.

Plain Flange, Drawings Above														Both			Bulkhead Flange, See ↗									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
		Flange and Flange Boss						Bore and Counterbore			Flange Bolts			Optional Pre-Inserted Silver Solder Ring										Bulkhead Bolts		
Nominal Size	Outside Diameter	Diameter A	Thickness B	Diameter C	Root Diam. D	Total Thick'ns E	Fillet F	Bore (Max) G	Counterbore (Max.) H	Depth of c'br I	Pitch Circle P.C.	Number of Bolts	Diameter of Bolts	Max J	±.005 K	±.010 L	Outside Diam. M	Total Thickness N	Body Thickness O	Rim Thickness P	Ring Insulation Width Q	Thickness of Q & Q' R	Diam Hole in Bulkhd S	Pitch Circle p.c.	Number of Bolts	Diameter of Bolts
1/4	.54	3 1/4	3/8	13/16	No Taper, D = C	7/8	1/4	.41	543	17/64	2 1/8	3	1/2	.100	072	.649	6 1/16	1 3/8	7/8	3/8	*1 3/16	1/4	3 1/2	4 7/8	6	1/2
3/8	675	3 3/8	"	1		15/16	"	.54	678	5/16	2 1/4	"	"	.117	.085	.807	6 1/8	1 7/16	"	"	*"	"	3 5/8	4 15/16	"	"
1/2	.84	3 9/16	"	1 5/32		1	"	.71	843	3/8	2 7/16	"	"	.149	.083	972	6 3/16	1 1/2	"	"	1 1/8	"	3 7/8	5 1/16	"	"
3/4	1.05	3 13/16	7/16	1 11/32		1 1/16	"	.92	1 053	13/32	2 11/16	4	"	154	.104	1.164	6 7/16	1 1/2	"	"	"	"	4 1/8	5 5/16	8	"
1	1.315	4 1/4	"	1 5/8		1 1/8	"	1.18	1.318	7/16	3 1/8	"	"	.154	.135	1434	6 7/8	1 9/16	"	"	"	"	4 1/2	5 3/4	"	"
1 1/4	1.66	4 1/2	"	2		1 1/4	5/16	1.53	1663	1/2	3 3/8	"	"	.185	.135	1.779	7 1/8	1 11/16	"	"	"	"	4 3/4	6	"	"
1 1/2	1.90	5 1/16	"	2 1/4		1 3/8	"	1.77	1.905	5/8	3 15/16	6	"	.217	.197	2.021	7 11/16	1 15/16	1	1/2	"	5/16	5 3/8	6 9/16	"	"
2	2 3/8	5 9/16	"	2 3/4		"	"	2.24	2.380	21/32	4 7/16	"	"	.217	.197	2.496	8 3/16	1 15/16	"	"	"	"	5 7/8	7 1/16	10	"
2 1/2	2 7/8	6 1/8	1/2	3 1/4		"	"	2.75	2.881	5/8	5	"	"	.217	.197	2.989	8 3/4	1 7/8	"	"	"	"	6 3/8	7 5/8	"	"
3	3 1/2	6 5/8	"	3 7/8		"	"	3.38	3.607	5/8	5 1/2	8	"	.185	.260	3.624	9 1/4	1 7/8	"	"	"	"	6 7/8	8 1/8	"	"
3 1/2	4	7 3/16	"	4 3/8		1 7/16	3/8	3.88	4.007	11/16	6 1/16	"	"	.217	.260	4.124	9 13/16	2	1 1/16	9/16	"	3/8	7 1/2	8 11/16	"	"
4	4 1/2	7 11/16	"	4 15/16		"	"	4.38	4.507	"	6 9/16	"	"	.217	.260	4.683	10 5/16	2	"	"	"	"	8	9 5/16	12	"
5	5 9/16	9 1/16	9/16	6	6 5/16	1 9/16	"	5.44	5.570	"	7 13/16	10	5/8	.217	.260	5.746	12 3/8	2 1/16	"	"	*1 7/16	"	9 1/2	10 15/16	"	5/8
6	6 5/8	10 1/8	"	7 1/16	7 3/8	1 11/16	7/16	6.44	6.632	3/4	8 7/8	12	"	.247	.260	6.812	13 7/16	2 1/4	1 1/8	5/8	*"	"	10 1/2	12	"	"
7	7 5/8	11 5/16	"	8 1/16	8 3/8	1 13/16	"	7.44	7.632	13/16	10	"	"	.217	.325	7.812	14 5/8	2 3/8	"	"	*"	"	11 3/4	13 9/16	14	"
8	8 5/8	12 3/8	5/8	9 1/8	9 7/16	2	"	8.44	8.632	15/16	11 1/16	14	"	.273	.385	8.812	15 11/16	2 1/2	"	"	*"	"	12 3/4	14 1/4	"	"
9	9 5/8	13 15/16	11/16	10 3/16	10 1/2	2 3/16	1/2	9.58	9.632	1	12 3/8	"	3/4	.310	.385	9.812	18 5/16	2 5/8	"	"	1 3/4	"	14 1/2	16 9/16	"	3/4
10	10 3/4	15	"	11 5/16	11 9/16	2 1/4	"	10.5	10.757	1 1/16	13 7/16	15	"	.314	.385	10.94	19 3/8	2 11/16	"	"	"	"	15 1/2	17 5/8	16	"

All Dimensions in Inches

*For these sizes $Q' = Q - \frac{1}{16}''$ (See pp. 510-513)

Composition Silver Soldered Flanges for Copper and Copper-Nickel Alloy Tubes and Pipes



BULKHEAD FLANGE

For Steam Pressures to 200 lbs psi up to 2" size, 300 lbs psi above 2" size. Temp to 650°F.

	Plain Flange, Drawings on Oppos. Page														Both			Bulkhead Flange, Above									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
			Flange and Flange Boss						Bore and Counterbore			Flange Bolts			Optional Pre-Inserted Silver Solder Ring										Bulkhead Bolts		
	Nominal Size	Outside Diameter	Diameter A	Thickness B	Diameter C	Root Diam. D	Total Thick'n's E	Fillet F	Bore (Max) G	Counterbore H	Depth of c'b'r I	Pitch Circle P.C.	Number of Bolts	Diameter of Bolts	Max. J	±.005 K	±.010 L	Outside Diam. M	Total Thickness N	Body Thickness O	Rim Thickness P	Ring Insulation Width Q	Thickness of Q & Q' R	Diam. Hole in Bulkh'd S	Pitch Circle p.c.	Number of Bolts	Diameter of Bolts
Steam to 200 lbs psi, 650°F.	1/4	.54	3 3/4	11/16	7/8	↑	1 3/16	1/4	.41	.543	17/64	2 5/8	3	1/2	.100	.072	.649	6 3/4	1 3/8	7/8	3/8	1 1/4	5/16	4	5 1/2	8	1/2
	3/8	.675	3 7/8	"	1 1/16		1 1/4	"	.54	.678	5/16	2 3/4	4	"	.117	.083	.807	6 7/8	1 7/16	"	"	"	"	4 1/8	5 5/8	"	"
	1/2	.84	4	"	1 1/4		1 5/16	"	.71	.843	3/8	2 7/8	"	"	.149	.083	.972	7	1 1/2	"	"	"	"	4 1/4	5 3/4	"	"
	3/4	1.05	4 5/16	"	1 7/16	D = C	"	"	.92	1.053	13/32	3 3/16	"	"	.154	.104	1.164	7 3/8	"	"	"	"	"	4 5/8	6 1/8	"	"
	1	1.315	5 1/16	3/4	1 3/4	Taper,	1 7/16	"	1.18	1.318	7/16	3 3/4	5	5/8	.154	.135	1.434	8 1/8	1 11/16	1	1/2	"	"	5 3/8	6 7/8	"	"
	1 1/4	1.66	5 3/8	13/16	2 1/8		1 5/8	5/16	1.53	1.663	1/2	4 1/16	"	"	.185	.135	1.779	8 3/8	1 13/16	"	"	"	3/8	5 5/8	7 1/8	10	"
	1 1/2	1.90	5 15/16	"	2 3/8		1 3/4	"	1.77	1.905	5/8	4 5/8	6	"	.217	.197	2.021	9	1 15/16	"	"	"	"	6 1/4	7 3/4	"	"
	2	2 3/8	6 1/2	"	2 7/8		"	"	2.34	2.380	21/32	5 3/16	7	"	.217	.197	2.496	10 1/4	2	1 1/16	9/16	1 1/2	"	7	8 3/4	"	5/8
Steam to 300 lbs psi & 650°F.	2 1/2	2 7/8	7 9/16	15/16	3 3/8	No	2 5/16	1/2	Bore to Suit inside diam. of Tube	2.882	1	6	8	3/4	.304	.197	2.989	11 3/8	2 7/16	"	"	"	"	8 1/8	9 7/8	"	"
	3	3 1/2	8 1/8	"	4		2 3/8	"		3.507	"	6 9/16	"	"	.383	.260	3.624	11 7/8	2 1/2	"	"	"	"	8 5/8	10 3/8	"	"
	3 1/2	4	8 11/16	1	4 1/2		2 7/16	"		4.007	"	7 1/8	9	"	.383	.260	4.124	12 1/2	2 9/16	1 1/8	5/8	"	1/2	9 1/4	11	12	"
	4	4 1/2	9 1/4	"	5	↓	2 5/8	9/16		4.507	1 1/8	7 11/16	"	"	.435	.260	4.683	13	2 3/4	"	"	"	"	9 3/4	11 1/2	"	"
	5	5 5/16	10 3/8	1 1/16	6 3/16	6 13/16	2 15/16	"		5.570	1 1/4	8 13/16	11	"	.493	.260	5.746	14 1/8	2 7/8	"	"	"	"	10 7/8	12 5/8	"	"
	6	6 5/8	11 15/16	1 3/16	7 5/16	7 15/16	3 1/8	5/8		6.632	1 3/8	10 5/16	12	7/8	.580	.380	6.812	16 3/8	3 1/8	1 3/16	11/16	1 3/4	"	12 1/2	14 5/8	"	3/4
	7	7 5/8	13 1/8	1 1/4	8 5/8	9 1/16	3 1/4	11/16		7.632	"	11 3/8	"	"	.493	.385	7.812	17 1/2	3 1/4	1 1/4	3/4	"	"	13 5/8	15 3/4	14	"
	8	8 5/8	14 3/4	1 5/16	9 3/8	10 3/16	3 1/2	"		8.632	1 1/2	12 3/4	13	1	.580	.385	8.812	19 1/8	3 1/2	1 5/16	13/16	"	"	15 1/4	17 3/8	16	"
	9	9 5/8	15 7/8	1 3/8	10 1/2	11 5/8	3 3/4	3/4		9.632	1 5/8	13 7/8	14	"	[illegible]	.385	9.812	20 1/4	3 3/4	1 3/8	7/8	"	"	16 3/8	18 1/2	"	"
	10	10 3/4	17	1 7/16	11 5/8	12 7/16	4	"		10.757	1 3/4	15	15	"	[illegible]	.385	10.934	21 3/8	4	1 7/16	"	"	"	17 1/2	19 5/8	18	"

Q'*, the Diam. of Insulating Washer, = Q, the Width of Insulating Ring, unless starred.
(See pp. 510-513)

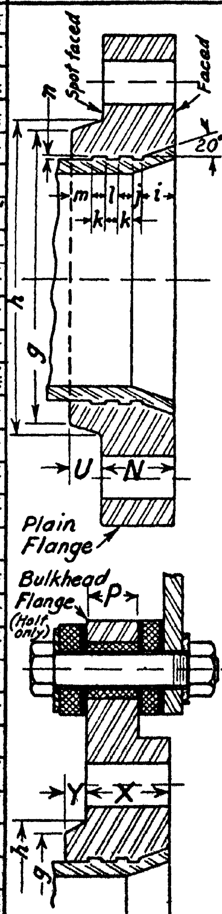
STEEL PIPES. PRESSURES TO 900. | STEEL FLANGES & B'LK'D FLANGES FOR STEAM, 101-300 LBS, & 650° F, MAXIMUM.

Thickness by formula, $T = \frac{\text{Pressure} \times \text{Diam}}{2(5000 + \text{Pressure})}$. Minimum T is ".095. Thickness for gage pressures of, lbs. (columns 3–8).

Plain Flange (columns 9–12; Boss: columns 10–12). Grooves cut on insides of flanges into which steel pipes are expanded. Sizes 1/4 to 1 1/4 have 3 k's and 2 l's (columns 13–18). Bulk'd Fl. (columns 19–21).

1 Nominal Size	2 Actual Outside Dia	3 -200	4 -300	5 450	6 600	7 750	8 900	9 Flange Thickness N	10 Depth of Boss U	11 Dia at edge g	12 Dia at root h	13 i	14 j	15 k	16 l	17 m	18 n	19 Root Thickness X	20 Edge Thickness P	21 Depth of Boss Y
1/4	54						095	9/16	7/16	1 1/16	1 9/16	5/32	1/16	3/32	5/32	3/16	1/32	7/8	3/8	1/8
1/2	84						095	9/16	7/16	1 11/16	1 13/16	5/32	1/16	3/32	5/32	3/16	1/32	7/8	3/8	1/8
3/4	105						095	5/8	7/16	2	2 1/8	6/32	1/16	3/32	3/16	3/16	1/32	7/8	3/8	3/16
1	1 5/16					095	.100	5/8	7/16	2 1/4	2 3/8	5/32	1/16	3/32	3/16	3/16	1/32	7/8	3/8	3/16
1 1/4	1 21/32				095	108	127	5/8	1/2	2 9/16	2 11/16	7/32	1/16	3/32	3/16	3/16	1/32	15/16	7/16	3/16
1 1/2	1 29/32			.095	102	.124	145	11/16	1/2	3 1/8	3 5/16	1/4	3/16	3/16	3/16	3/16	1/32	1	1/2	3/16
2	2 3/8		.095	.098	.127	155	181	3/4	1/2	3 11/16	3 7/8	1/4	3/16	3/16	3/16	1/4	1/32	1 1/16	9/16	3/16
2 1/2	2 7/8		095	119	154	187	219	13/16	1/2	4 1/4	4 7/16	1/4	1/4	3/16	3/16	1/4	1/32	1 1/16	9/16	1/4
3	3 1/2	095	099	144	187	228	267	13/16	9/16	4 13/16	5	5/16	1/4	3/16	3/16	1/4	1/32	1 1/16	9/16	5/16
3 1/2	4	.095	.113	165	.214	261	305	7/8	9/16	5 3/8	5 9/16	5/16	1/4	7/32	3/16	1/4	1/32	1 1/8	5/8	5/16
4	4 1/2	.095	127	186	241	.293	.343	15/16	9/16	5 15/16	6 1/8	5/16	5/16	7/32	3/16	1/4	3/64	1 1/8	5/8	3/8
4 1/2	5	.096	142	206	268	.326	.382	1	9/16	6 1/2	6 3/4	5/16	5/16	7/32	7/32	9/32	3/64	1 1/8	5/8	7/16
5	5 9/16	107	157	230	298	.363	424	1	5/8	7 1/16	7 3/8	5/16	5/16	7/32	7/32	11/32	3/64	1 1/8	5/8	1/2
5 1/2	6 1/8	118	173	.253	328	.399	.467	1 1/16	5/8	7 5/8	7 7/8	3/8	5/16	7/32	7/32	11/32	3/64	1 1/8	5/8	9/16
6	6 5/8	127	.187	.273	.355	432	.505	1 1/8	5/8	8 3/16	8 7/16	3/8	5/16	1/4	7/32	11/32	3/64	1 1/8	5/8	5/8
6 1/2	7 1/8	137	202	.294	382	466	544	1 3/16	5/8	8 13/16	9 1/16	3/8	5/16	1/4	1/4	3/8	3/64	1 3/16	11/16	5/8
7	7 5/8	147	216	.315	408	497	.582	1 3/16	11/16	9 3/8	9 5/8	7/16	5/16	1/4	1/4	3/8	3/64	1 3/16	11/16	11/16
7 1/2	8 1/8	156	230	.335	435	530	.620	1 1/4	11/16	9 15/16	10 1/4	7/16	3/8	1/4	1/4	3/8	3/64	1 1/4	11/16	11/16
8	8 5/8	166	.249	.356	462	.563	.658	1 5/16	11/16	10 1/2	10 13/16	7/16	3/8	1/4	1/4	7/16	3/64	1 5/16	11/16	11/16
8 1/2	9 1/8	175	258	377	489	595		1 3/8	11/16	11 1/16	11 5/16	1/2	3/8	1/4	1/4	7/16	1/16	1 3/8	11/16	11/16
9	9 5/8	185	272	.397	516	.628		1 3/8	3/4	11 5/8	11 7/8	1/2	3/8	9/32	1/4	7/16	1/16	1 3/8	11/16	3/4
9 1/2	10 1/4	195	.290	423	.549	.668		1 7/16	3/4	12 3/16	12 1/2	1/2	3/8	9/32	1/4	1/2	1/16	1 7/16	11/16	3/4
10	10 3/4	207	304	.444	.576	.701		1 1/2	3/4	12 3/4	13 1/8	1/2	3/8	9/32	9/32	17/32	1/16	1 1/2	3/4	3/4
11	11 3/4	.226	.333	.485	.629			1 9/16	13/16	13 7/8	14 3/16	9/16	3/8	9/32	9/32	19/32	1/16	1 9/16	3/4	13/16
12	12 3/4	.245	.361	.526	683			1 5/8	15/16	15 1/8	15 3/8	9/16	1/2	9/32	9/32	21/32	1/16	1 5/8	3/4	15/16
13	14	.263	.396	.578				1 11/16	1	16 1/4	16 1/2	5/8	1/2	9/32	9/32	23/32	1/16	1 11/16	3/4	1
14	15	.288	.425	.619				1 13/16	1	17 3/8	17 5/8	5/8	1/2	5/16	5/16	3/4	1/16	1 13/16	3/4	1
15	16	.308	.453	.660				1 13/16	1 1/16	18 3/8	18 5/8	5/8	1/2	5/16	5/16	13/16	1/16	1 13/16	3/4	1 1/16

22 — NOTE: Columns 3, 12, 13, 14, 18 and 22-27 of page 557 also apply to these steel flanges.



(See page 513) 1936

STEEL FLANGES FOR H.P. STEEL TUBES & PIPES.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Nominal Size	Actual O.D.	FOR STEAM. PRESSURE, 301-400 LBS; 650°F. MAX. FOR BOILER FEED LINES: 401-600 LBS, 425°F. MAX. "SPHERICAL BACK, VAN STONE" TYPE																			FOR STEAM: PRES 401-600 LBS; 850°F. MAX. FOR BOILER FEED LINES: 601-750 LBS, 425°F. MAX. "SPHERICAL BACK, VAN STONE". FOR P see Col. 12														
														Plain Fl.			Bulkhead			Min										Plain Fl.			Bulkhead		
		M	N	U	S	o	p	q	W	X	P	Y	c	No.	Dia.	p.c.	No.	Dia.	p.c.	r	M	N+X	U+Y	S	o	p	q	W	c	No.	Dia.	p.c.	No.	Dia.	p.c.
1	1 5/16	4 7/8	11/16	3/8	2 1/8	1 7/8	3 7/32	1/8	8 1/8	1 1/16	3/8	-	5 5/8	4	5/8	3 1/2	8	1/2	6 5/8	1/8	4 7/8	11/16	11/16	2 1/8	1 7/8	3 7/32	1/8	8 1/8	5 5/8	4	5/8	3 1/2	8	1/2	6 5/8
1 1/4	1 21/32	5 1/4	13/16	5/16	2 1/2	2 3/8	4 1/32	3/16	9 1/8	1 1/8	3/8	-	5 1/2	4	5/8	3 7/8	8	5/8	7 1/4	1/8	5 1/4	13/16	11/16	2 1/2	2 3/8	4 1/32	3/16	9 1/8	5 1/2	4	5/8	3 7/8	8	5/8	7 1/4
1 1/2	1 29/32	6 1/8	7/8	3/8	2 3/4	2 3/4	4 5/8	1/4	10	1 1/4	1/2	-	6 3/8	4	3/4	4 1/2	8	5/8	8 1/8	1/8	6 1/8	7/8	3/4	2 3/4	2 3/4	4 5/8	1/4	10	6 3/8	4	3/4	4 1/2	8	5/8	8 1/8
2	2 3/8	6 1/2	1	7/16	3 5/16	3 1/2	5 11/16	1/4	10 5/8	1 7/16	9/16	-	7	8	5/8	5	12	5/8	8 3/4	1/8	6 1/2	1	13/16	3 9/16	3 1/2	5 11/16	1/4	10 5/8	7	8	5/8	5	12	5/8	8 3/4
2 1/2	2 7/8	7 1/2	1 1/8	1/2	3 15/16	4	6 25/32	1/4	11 5/8	1 7/16	9/16	3/16	8	8	3/4	5 7/8	12	5/8	9 3/4	1/8	7 1/2	1 1/8	7/8	4 5/16	4	6 25/32	1/4	11 5/8	8	8	3/4	5 7/8	12	5/8	9 3/4
3	3 1/2	8 1/4	1 1/4	9/16	4 5/8	4 7/8	8 1/4	1/4	12 3/8	1 5/8	5/8	3/16	8 3/4	8	3/4	6 5/8	12	5/8	10 1/2	1/8	8 1/4	1 1/4	7/8	5	4 7/8	8 1/4	1/4	12 3/8	8 3/4	8	3/4	6 5/8	12	5/8	10 1/2
3 1/2	4	9	1 3/8	9/16	5 1/4	5 3/8	6 1/4	1/4	13 1/8	1 5/8	5/8	5/16	9 1/2	8	7/8	7 1/4	12	5/8	11 1/4	1/8	9	1 3/8	15/16	5 1/2	5 3/8	6 1/4	1/4	13 1/8	9 1/2	8	7/8	7 1/4	12	5/8	11 1/4
4	4 1/2	10	1 3/8	5/8	5 3/4	6 1/16	7	1/4	14 1/8	1 5/8	5/8	3/8	10 1/2	8	7/8	7 7/8	12	5/8	12 1/4	3/16	10	1 1/2	1 1/4	6 1/8	6 1/16	7	1/4	14 1/8	10 1/2	8	7/8	7 7/8	12	5/8	12 1/4
4 1/2	5	10 1/2	1 7/16	5/8	6 3/8	6 5/8	7 11/16	1/4	14 5/8	1 5/8	5/8	7/16	11	8	7/8	8 1/2	16	5/8	12 3/4	3/16	10 1/2	1 5/8	1 5/16	6 9/16	6 5/8	7 11/16	1/4	14 5/8	11	8	1	8 1/2	16	5/8	12 3/4
5	5 9/16	11	1 1/2	5/8	7	7 7/16	8 11/16	1/4	15 5/8	1 5/8	5/8	1/2	11 1/2	8	7/8	9 1/4	16	5/8	13 1/4	3/16	11	1 3/4	1 3/8	7 5/16	7 3/8	8 13/32	1/4	15 1/8	11 1/2	8	1	9 1/4	16	5/8	13 1/4
5 1/2	6 1/8	11 1/2	1 9/16	5/8	7 5/8	7 3/4	9 1/8	1/4	15 5/8	1 5/8	5/8	9/16	12	12	7/8	9 3/4	16	5/8	13 3/4	3/16	11 1/2	1 13/16	1 7/16	8	7 3/4	9 1/8	1/4	15 5/8	12	12	7/8	9 3/4	16	5/8	13 3/4
6	6 5/8	12 1/2	1 5/8	5/8	8 1/8	8 3/8	9 27/32	1/4	16 5/8	1 5/8	5/8	5/8	13	12	7/8	10 5/8	16	5/8	14 3/4	3/16	12 1/2	1 7/8	1 1/2	8 9/16	8 3/8	9 27/32	1/4	16 5/8	13	12	1	10 5/8	16	5/8	14 3/4
6 1/2	7 1/8	13	1 11/16	11/16	8 3/4	8 7/8	8 5/32	1/4	17 3/4	1 11/16	11/16	11/16	13 1/2	12	7/8	11 1/4	16	3/4	15 5/8	1/4	13	2	1 3/4	9 1/4	8 7/8	8 5/32	1/4	17 3/4	13 1/2	12	1	11 1/4	16	3/4	15 5/8
7	7 5/8	14	1 3/4	11/16	9 1/4	9 3/8	8 5/8	3/8	18 3/4	1 3/4	11/16	11/16	14 1/2	12	1	11 7/8	16	3/4	16 5/8	1/4	14	2 1/16	1 15/16	9 3/4	9 3/8	8 5/8	3/8	18 3/4	14 1/2	12	1 1/8	11 7/8	16	3/4	16 5/8
7 1/2	8 1/8	14 3/8	1 13/16	3/4	9 3/4	10	9 5/32	3/8	19 1/8	1 13/16	11/16	3/4	14 7/8	12	1	12 3/8	16	3/4	17	1/4	14 1/2	2 1/8	2 1/8	10 3/8	10	9 5/32	3/8	19 1/4	15	12	1 1/8	12 1/2	16	3/4	17 1/8
8	8 5/8	15	1 7/8	13/16	10 1/4	10 1/2	9 5/8	3/8	19 3/4	1 7/8	11/16	13/16	15 1/2	12	1	13	16	3/4	17 5/8	1/4	15	2 3/16	2 5/16	10 11/16	10 1/2	9 5/8	3/8	19 3/4	15 1/2	12	1 1/8	13	16	3/4	17 5/8
8 1/2	9 1/8	15 3/4	1 15/16	1 3/4	10 7/8	11	10 1/8	3/8	20 1/2	1 15/16	11/16	1 3/4	16 1/4	12	1 1/8	13 1/2	16	3/4	18 3/8	5/16	16 1/2	2 5/16	2 3/8	11 3/4	11	10 1/8	3/8	21 1/4	17	12	1 1/4	14 1/4	16	3/4	19 1/8
9	9 5/8	16 1/4	2	1 13/16	11 3/8	11 9/16	10 11/16	3/8	21	2	11/16	1 13/16	16 3/4	12	1 1/8	14	16	3/4	18 7/8	5/16	17	2 3/8	2 3/8	12 1/4	11 9/16	10 11/16	3/8	21 3/4	17 1/2	12	1 1/4	14 3/4	16	3/4	19 5/8
9 1/2	10 1/4	17	2 1/16	1 7/8	12	12 1/16	11 1/4	3/8	21 3/4	2 1/16	11/16	1 7/8	17 1/2	16	1 1/8	14 3/4	16	3/4	19 5/8	5/16	17 3/4	2 7/16	2 7/16	13	12 1/16	11 1/4	3/8	22 1/2	18 1/4	16	1 1/8	15 1/2	16	3/4	20 1/8
10	10 3/4	17 1/2	2 1/8	1 7/8	12 5/8	12 9/16	11 25/32	3/8	22 1/4	2 1/8	3/4	1 7/8	18	16	1 1/8	15 1/4	20	3/4	20 1/8	5/16	19 1/2	2 1/2	2 1/2	13 3/4	12 9/16	11 25/32	3/8	24 1/4	20	16	1 1/4	17	20	3/4	22 1/8
10 1/2	11 1/4	18	2 1/8	1 15/16	13 1/8	13 1/16	12 1/4	3/8	22 3/4	2 1/8	3/4	1 15/16	18 1/2	16	1 1/8	15 3/4	20	3/4	20 5/8	3/8	20	2 9/16	2 9/16	14 3/8	13 1/16	12 1/4	3/8	24 3/4	20 1/2	16	1 1/4	17 1/2	20	3/4	22 5/8
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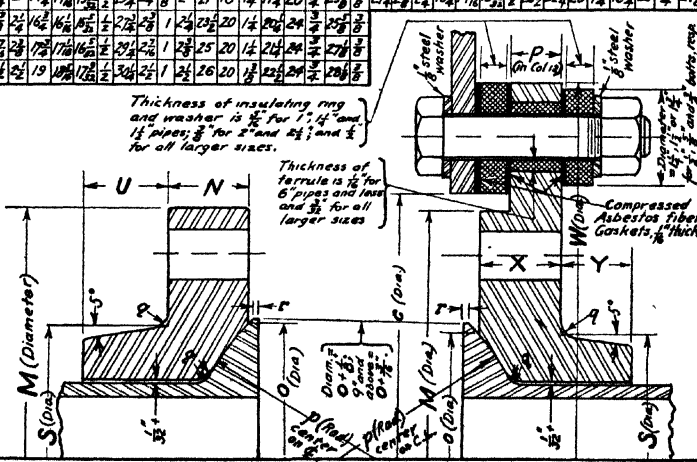
13	14	23	2 3/8	2 1/4	16 3/4	16 1/16	15 5/32	1/2	27 3/4	2 3/8	1	2 1/4	23 1/2	20	1 1/4	20 1/4	24	3/4	25 5/8	3/8															
14	15	24 1/2	2 7/16	2 3/8	17 3/4	17 1/16	16 5/32	1/2	29 1/4	2 7/16	1	2 3/8	25	20	1 1/4	21 1/4	24	3/4	27 1/8	3/8															
15	16	25 1/2	2 1/2	2 1/2	19	18 5/16	17 9/32	1/2	30 1/4	2 1/2	1	2 1/2	26	20	1 3/8	22 1/2	24	3/4	28 1/8	3/8															



GENERAL INDEX

GENERAL INDEX

The light number is the page, the bold-faced number is the article.

E

F

V

W

X

Y

Z